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Final Report

INSTREAM FLOW REQUIREMENTS FOR SUPPORTING RIPARIAN ECOSYSTEMS IN UPLAND WATERSHEDS OF CENTRAL NEVADA: AN INTEGRATED STUDY

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SUMMARY

Riparian corridors within upland watersheds of central Nevada locally contain wet meadow ecosystems that support much of the region's biodiversity. Almost without exception, these meadow complexes occur upstream of alluvial fans that have built across the valley floor, and which are referred to here as side valley alluvial fans. Regional stratigraphic data suggest that meadows have existed in these geomorphic positions for at least the past 4,000 years. However, the morphology of both the meadows and the axial channels were significantly modified during a major episode of aggradation that occur from approximately 2,500-1,960 YBP as well as more recent episodes of channel incision. The sedimentology and stratigraphy of the deposits upstream of the side valley fans, and which underlie the meadows, is extremely complex, consisting of laterally discontinuous alluvial fan deposits, axial channel fills, lobate gravel lenses, and fine-grained mineral and peat layers.

The interactions between surface and groundwater flow systems were examined for two sites (Big Creek and Corral Canyon) which are thought to be representative of wet meadow ecosystems in the area. At the Big Creek site, a perennial stream traverses the wet meadow and connects upstream with downstream reaches of the axial channel. Immediately upstream of wet meadow areas, water is lost from the axial channel into the adjacent alluvium, but as the wet meadow is approached, flow patterns are reversed and water is delivered to the channel from the surrounding alluvium. Shallow groundwater flow (upper 10 m or so) is complicated by the complexity of the local stratigraphy, but is generally downvalley, and along gaining stream reaches, toward the channel. Fluctuations in the water table in areas with wet meadow vegetation are minimal and vertical flow gradients are consistently upward. These flow patterns suggest that waters within areas of wet meadow vegetation are derived from the upwelling of water moving downvalley through alluvial materials which encounter a restriction in the width or thickness of the aquifer. This suggestion is supported by preliminary isotopic data, anion/cation water chemistry, and shallow seismic geophysical surveys.

The Corral Canyon site differs from the Big Creek site in that it lacks a perennial channel. Rather, an entrenched axial channel begins in a headcut at the downstream margins of the site where valley widths are constricted by bedrock and alluvial fan deposits and valley floor gradients increase significantly. Moreover, the shallow groundwater flow system is more complex than that observed at the Big Creek site, locally exhibiting both unconfined and confined flow conditions. The increased complexity in flow patterns can be partly attributed to the nature of the valley fill deposits, particularly the occurrence of fine-grained layers that result in locally confined flow conditions. Groundwater flow in the area is similar to the Big Creek site in that water table (and potentiometric surface) fluctuations are minimal in areas of wet meadow vegetation, and vertical flow gradients are consistently upward. In addition, groundwater flow patterns, geochemical data, and seismic surveys suggest that the primary source of water to the meadow is water moving downvalley through the alluvial valley fill that is forced to the surface by constrictions in the width and/or thickness of the alluvial aquifer.

Preliminary data suggest that a principal reduction in the cross-sectional area of the alluvial aquifer is due to bedrock highs beneath the valley fill that reduce aquifer thicknesses. These bedrock highs appear to correspond to large, side valley fans, explaining the consistent occurrence of wet meadows upstream of fan complexes. We hypothesize that the alluvial fan deposits covered and protected the underlying bedrock from erosion during previous (perhaps pre-Holocene?) valley cutting.

Recent studies in the area have shown that most of the axial streams within the upland basins of central Nevada are incising during major runoff events (e.g., 1983, 1995). Entrenchment was documented during this study for the Big Creek site. Thus, an estimation of the instream flows required to maintain channel morphology, which is based on an assumption of channel stability, was not possible for the field sites examined in this investigation. However, an analysis of particle entrainment suggests that relatively frequent flows (perhaps those that occur once every five to ten years) are capable of effectively molding the channel bed and bank materials.

Studies of other streams in the western U.S. demonstrate that channel entrenchment may directly result in a lowering of water table levels and a change in riparian plant communities. A continuous supply of water to the wet meadows from upvalley areas suggests that the affects of channel cutting on water table levels may be minimal at the sites examined in this study. However, it is important to recognize that the impacts of entrenchment on the shallow groundwater flow systems are poorly understood and should be more extensively examined using numerical modeling approaches. In addition, the data suggest that the wet meadow systems may be significantly impacted by shallow groundwater withdrawals. Assessment of the potential impacts of water diversions on these ecosystems is likely to require a watershed scale, mass balance approach.

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INTRODUCTION

In the 19^{th} century, British engineers were delegated the task of designing and constructing canals in India that, for a specific discharge and sediment load, were nonfilling and nonscouring (Ackers, 1972). These efforts led to a basic understanding of the relations between discharge, sediment transport, and channel form. In recent years, these originally defined relationships have been more extensively examined using numerically intensive computer codes, and their utilization in the design of canal systems has produced excellent results. Unfortunately, however, their application to river systems, characterized by a greater range of flow, sediment size, and material load, has proven difficult at best. Nonetheless, it is generally accepted that channel morphology is delicately adjusted over a period of years to the prevailing hydrologic and sedimentologic regime. It follows, then, that the diversion and regulation of stream flows, which are often accompanied by changes in sediment load and size, may lead to alterations in channel dimensions, cross-sectional form, pattern, and planimetric configuration (Ritter et al., 1995; Williams and Wolman, 1984). Given that the geomorphic setting provides the physical framework for aquatic and riparian ecosystems, channel adjustments can also result in alterations in the composition, density, and geographical patterns of biological communities, and the loss of habitats within the channel and upon the adjacent floodplain (Gregory et al., 1991). The potential consequences of altered stream flow has led to a desire to minimize the downstream impacts of surface water diversions and shallow groundwater withdrawals. In fact, minimization of the impacts to stream and riparian resources is mandated by a number of state and federal statutes (Andrews and Nankervis, 1995). For example, the need to preserve channel forming flows on National Forest lands is dictated by the Organic Administration Act of 1897 which states:

> "...No National Forest shall be established except to improve and protect the forest within the boundaries or for the purpose of securing favorable conditions of water flows..."

In order to insure "favorable conditions of water flows" it has been recognized that there is a need to determine the degree to which the hydrologic regime can be changed without altering channel morphology, or impairing the integrity of stream and riparian resources. The basis for these determinations has rested, in part, on the concept of a dominant or effective discharge as initially defined by Wolman and Miller (1960). Implicit within this concept is the argument that channel form is maintained by a limited range of flows (known as the dominant or effective discharge) that not only transport the most sediment, but are capable of entraining bed and bank material, thereby allowing a modification in channel morphology. It is generally accepted that the effective discharge has a magnitude and frequency equivalent to bankfull (Wolman and Miller, 1960; Emmett, 1975; Andrews, 1994; Battalla and Sala, 1995, Andrews and Nankervis, 1995). However, a number of investigators have questioned whether flows approaching the bankfull condition represent the dominant discharge in all river systems (Pickup and Warner, 1976; Richards, 1982; Ashmore and Day, 1988; Nash, 1994), particularly within coarse-grained channels in mountainous terrains, or those found in arid environments (Baker, 1977). Moreover, it has been suggested that in some environments, bankfull channel capacity and form can be maintained where substantial (perhaps as much as 60 %) of the natural flow is diverted from the stream (Andrews and Nankervis, 1995).

In order to maintain channel morphology, the input of sediment to the channel must equal the outflow over a period of years to decades. Failure of this equilibrium state will result in channel adjustments, including the potential loss of channel capacity. In addition, the hydrologic regime must be able to entrain bed and bank materials, thereby effecting a change in channel form. Given these constraints, most studies attempting to define the minimum instream flows required to maintain the existing shape and sedimentology of the channel have been based on an analysis of the discharge(s) required to initiate particle motion within the channel perimeter and/or the rate at which sediment is transported through the reach during varying hydrologic conditions (Rosgen et al., 1986; Andrews and Nankervis, 1995).

In addition to recognizing the importance of maintaining a stable channel configuration, a number of investigators (and land-managers) have taken a more holistic approach, arguing that the analysis also needs to document the minimum flows required to sustain stream side vegetation. With regards to channel shape, the binding effects of the root mass and the influence of vegetation on channel roughness may limit stream bank erosion. In addition, vegetation along the channel margins and upon the floodplain generally provides an important habitat for a number of animal species, particularly in arid regions of the western U.S.

The analysis of the minimum flows required to maintain riparian vegetation has proven to be a complicated process in that it is dependent on a large number of parameters including geomorphic disturbances such as the erosion and deposition of floodplain and terrace deposits, the magnitude and duration of floodplain inundation, soil texture, and soil moisture. Moreover, plant communities in some areas may be highly dependent on the depth to and fluctuations in the water table, which is not only governed by the instream discharges, but by the shallow groundwater flow system. Thus, any determination of the minimum instream flows required to maintain riparian vegetation must focus on both the water within the channel, and the movement and controls on groundwater within the adjacent alluvium. Given the complexities involved, the analysis of instream flows required to maintain channel form and stream side vegetation are typically conducted on the reach scale over which the appropriate data can be collected. These data are subsequently extrapolated to other settings with similar geomorphic, hydrologic, and biotic characteristics.

PROJECT OBJECTIVES

Riparian corridors within upland watersheds in the Great Basin of central Nevada encompass less than 2 % of the total land area. Nonetheless, they contain a disporportionally large percentage of the region's biodiversity, providing habitat for neotropical migrants (Saab and Groves 1992), numerous endemics, and a large number of endangered species (Hubbard, 1977). Many of these upland watersheds fall within the Toiyabe-Humbolt National Forest, and in recent years, there has been a growing need to determine the instream flows required to maintain the riparian vegetation within these basins as well as within other watersheds of mountainous environments of the western U.S. Of particular importance are mesic and wet meadow ecosystems which locally occur along the alluvial valley floors.

The primary objective of this investigation is to determine the instream flows required to maintain meadow ecosystems which locally occur along the riparian corridor of upland

watersheds in central Nevada. The objective was accomplished by (1) characterizing the surface and groundwater flow systems, (2) determining the interactions between these hydrologic components, and (3) analyzing the relations between the vegetational communities, and the depths to and fluctuations in water table levels. This report focuses on the interactions of the surface and groundwater flow systems and the controls on water table fluctuations. The relations between vegetation and water table characteristics (depths and annual fluctuations) were determined largely by Dr. Jeanne Chambers and her colleagues at the Rocky Mountain Research Station, and have been summarized elsewhere (Castelli, 1999; Chambers, 1999). In addition to characterizing the interactions between surface and groundwater flow systems we also examined the minimum instream flows required to maintain channel form, and the problems encountered while performing these analyses within the upland basins of central Nevada.

REGIONAL GEOGRAPHIC SETTING

The physiography of the Great Basin of central Nevada is dominated by southwest-northeast trending, fault-blocked ranges that are separated by intermontane basins (Figure 1). The watersheds within upland areas are typically small, ranging from a few square kilometers to more than 100 km^2 in size, and that occur at elevation ranging from about 1,850 to 3,200 m. Annual precipitation varies significantly with altitude, changing from roughly 20 cm at the basin mouth to as much 45 cm at upper elevations. Approximately 60% of the precipitation occurs in the form of snow during the winter months. Peak runoff is in response to snowmelt in late May or early June, but localized convective summer storms can result in flash floods. At low to middle elevations, Wyoming big sagebrush (Artemisia tridentata spp. wyomingensis) communities are interspersed with Utah juniper (Juniperus osteosperma) and single leaf pinyon (Pinus monophylla) woodlands. At higher elevations, mountain brush vegetation is dominant, including mountain big sagebrush (Artemisia tridentata spp. vaseyana) and limber pine (Pinus flexilis).

The axial channel systems are typically characterized by steep slopes and gravel dominated bed and banks with flows ranging from approximately 0.015 to 2.00 m^3/s (Hess and Bohman, 1996; M. Amacher, personal communication). In general, riparian vegetation consists of stringers of quaking aspen (Populus tremuloides), narrow leaf cottonwood (Populus angustifolia), river birch (Betula occidentalis), willows (Salix spp.), and meadow communities (USDA Forest Service, 1996). At the base of the mountains, streams flow onto alluvial fans and land management changes from USDA Forest Service to USDI Bureau of Land Management. Small inholdings of private property often exist at these areas, and a majority of the streams are diverted to these inholdings or to private ranches lower in the intermontane basins.

SELECTION AND GEOGRAPHIC SETTING OF STUDY SITES

In conjunction with Drs. Larry Schmidt, Jeanne Chambers, and participants of the ongoing USDA Ecosystem Management Project, two field sites were selected for detailed analysis. Both sites are thought to be representative of riparian/meadow ecosystems that occur within upland watersheds of central Nevada, and exhibit systematic variations in plant community types, allowing for a detailed analysis of the relations between the shallow groundwater flow system and the composition of the overlying vegetation. The larger of the two

Basin Names

- ● Big Creek
- ▼ Barley Creek
- ▲ Kingston Canyon
- ■ San Juan, Cottonwood, and Washington Creeks
- ◆ Stoneberger Creek and Corral Canyon

Figure 1. Location of study basins in central Nevada. Map courtesy of Ray Sterner at http://fermi.jhuapl.edu/states/.

field sites is positioned within the upper reaches of Corral Canyon, a drainage basin located within the Toquima Range (Figure 1). Geomorphically, the meadow is positioned upstream of a valley constriction created by a bedrock outcrop and a large alluvial fan that has built away from the valley sides (Figure 2a). Although the meadow contains a number of small gullies fed by groundwater flow, a channel linking reaches upstream and downstream of the meadow is absent. A highly incised channel does exist immediately downstream of the meadow where valley gradients increase dramatically. This channel terminates upstream in a headcut developed in alluvial materials at the toe of the side valley fan that forms the downstream boundary of the meadow complex.

The second field site is located in the Big Creek basin within the Toiyabe Range (Figure 1). Like the meadow in Corral Canyon, it is positioned upstream of a valley constriction created by an alluvial fan that nearly extends across the entire width of the valley floor (Figure 2b). It differs from Corral Canyon, however, in that a perennial channel, incised approximately 1 m below the valley floor, traverses the meadow system and links upstream and downstream reaches of the basin. It also exhibits several small, spring feed gullies that flow across the wet meadow to the incised axial channel.

METHODS

Characterization of the shallow groundwater flow system requires an understanding of the sedimentology and stratigraphy of the alluvial valley fill as well as the hydrologic properties of the alluvial deposits. The regional stratigraphy of the valley fill in the upland basins has been documented as part of the USDA Ecosystem Management Project, and is based on the description of alluvial deposits exposed in the channel banks of San Juan and Cottonwood Creeks of the Toiyabe Range, Stoneberger Creek within the Toquima Range, and Barley Creek within the Monitor Range (Figure 1). Reconnaissance level investigations were also carried out along Washington Creek, Kingston Canyon, and Antone Creek (Figure 1). Stratigraphic units were defined within individual bank sections on the basis of grain-size distribution, sediment color and lithology, degree of sediment weathering, and topographic/stratigraphic position. Once the units had been delineated, the stratigraphic sections were described and mapped in detail to document the geometry of unit boundaries, the continuity of stratigraphic units and facies, the location of collected sediment and radiocarbon samples, and the presence of surface or buried soils. The grain-size of the >2 mm sediment fraction was determined using an approach modified from Wolman (1954), whereas the grain-size distribution of the <2 mm sediment faction was performed using wet-sieving and pipette techniques modified from Singer and Janitzky (1986). Soil profiles developed in the stratigraphic units were described according to the methods and nomenclature put forth by the Soil Conservation Service (1981) and Birkeland (1984).

In addition to describing the deposits within the banks of the incised channels, a number of sediment cores were obtained and characterized from wet meadow systems within Big Creek, Corral Canyon, and Kingston Canyon. The cores from Corral and Kingston Canyons, which are characterized by relatively fine-grained materials, were obtained using a Livingston coring device. The valley fill within the Big Creek site tended to be much coarser-grained, and could

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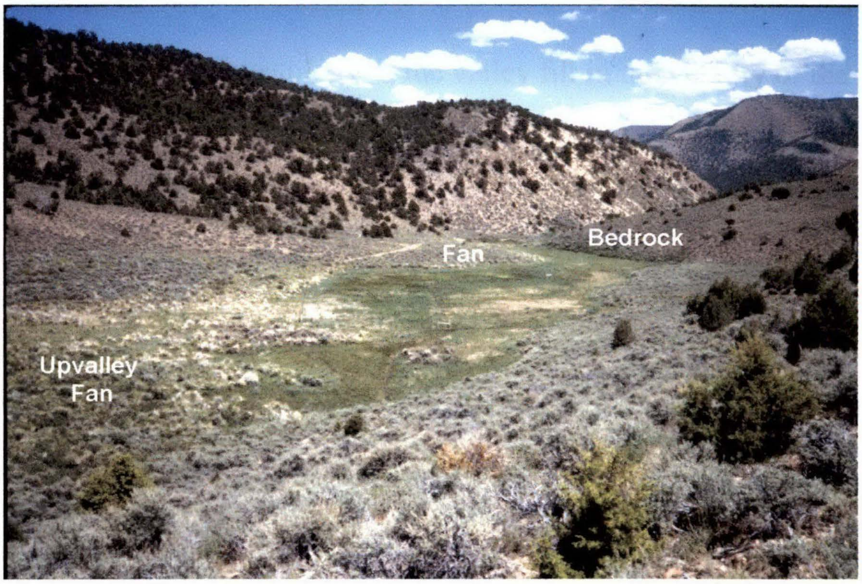

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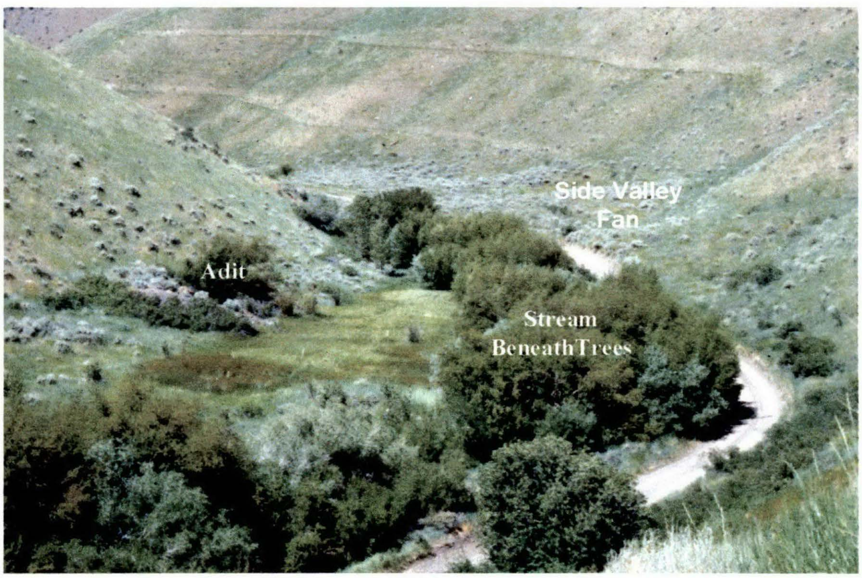


Figure 2. (A) The Corral Canyon study site within the Toquima Range; (B) the Big CreekStudy Site within the Toiyabe Range.

not be sampled with the Livingston device. Thus, several cores were collected using a 30 cm (12") split spoon sampler attached to a hammer driver. All of the cores were characterized using the procedures outlined above.

Given the variability in the sedimentology of the valley fill in the vicinity of the wet meadows (which ranges from fine-grained, organic rich sediments to coarse-grained [gravelly] alluvial fan deposits), it was necessary to utilize a variety of methods to determine the hydraulic conductivity of the materials. These methods included slug-tests (after Hvorslev, 1951) within monitoring wells (conducted using a pressure transducer and data logger), falling head permeameter experiments on core samples (Klute and Dirksen, 1986), and Geulph Infiltrometer tests on alluvial fan deposits (Reynolds et al., 1983).

Characterization of the shallow groundwater flow system within the two study areas was based on data from a large number of piezometers. The piezometers consisted of 1.9 cm (0.75") thin-walled, electrical conduit (EMT)(Figure 3). The end of the conduit was plugged with a carriage bolt, or a machined drive point, and driven into the materials using a metal fence post driver. In most cases, the lower 0.5 to 1 m of pipe was slotted on both sides using a power hacksaw. At some sites, however, nests of piezometers were installed to determine vertical flow gradients, and the pipes were left unslotted. After installation of the latter piezometers, the drive points were driven out of the pipes to allow for the easy flow of water into the piezometers. A total of 54 piezometers were installed at the Big Creek site; 81 piezometers were installed at the Corral Canyon site. Specifications for the piezometers are presented in Appendix A, Tables A-1 and A-2.

In order to conduct slug-tests for hydraulic conductivity measurements, and to sample groundwaters for geochemical analyses, a total of 7 monitoring wells were installed within the Big Creek site in the summer of 1997. In addition, 4 monitoring wells were installed in the Corral Canyon Site in the summer of 1999. These monitoring wells are constructed of 5 cm (2") PVC riser pipe that was threaded onto 20 slot per inch PVC screen stock. Screened sections were covered with standard well sock. The bottom of the PVC pipe was capped prior to placement in a hand-augured hole. The outside perimeter of the hole (above the slotted lower reach) was sealed using bentonite to insure that surface-waters did not enter the wells. All monitoring wells were finished below the lowest determined water level.

The elevation of the piezometers and monitoring wells were documented at each site using a Leica Total Station. All elevations were determined relative to a benchmark that was installed prior to conducting the field surveys. Reliability of the data was assessed by determining the elevation of the piezometer and well sites from two separate locations (where trees and other vegetation allowed a view of the sites). In generally, the repeat measurements of the sites were within 1 cm of each other (Appendix A, Tables A-3, A-4). Weather permitting, water level data have been collected at semi-monthly intervals for each of the piezometers and wells using an electrical water level seeker. Initial construction of the potentiometric surface maps was performed using SURFER™ (Golden Software, 1995). These maps were subsequently compared to the site's topographic maps and modified accordingly using manual methods.

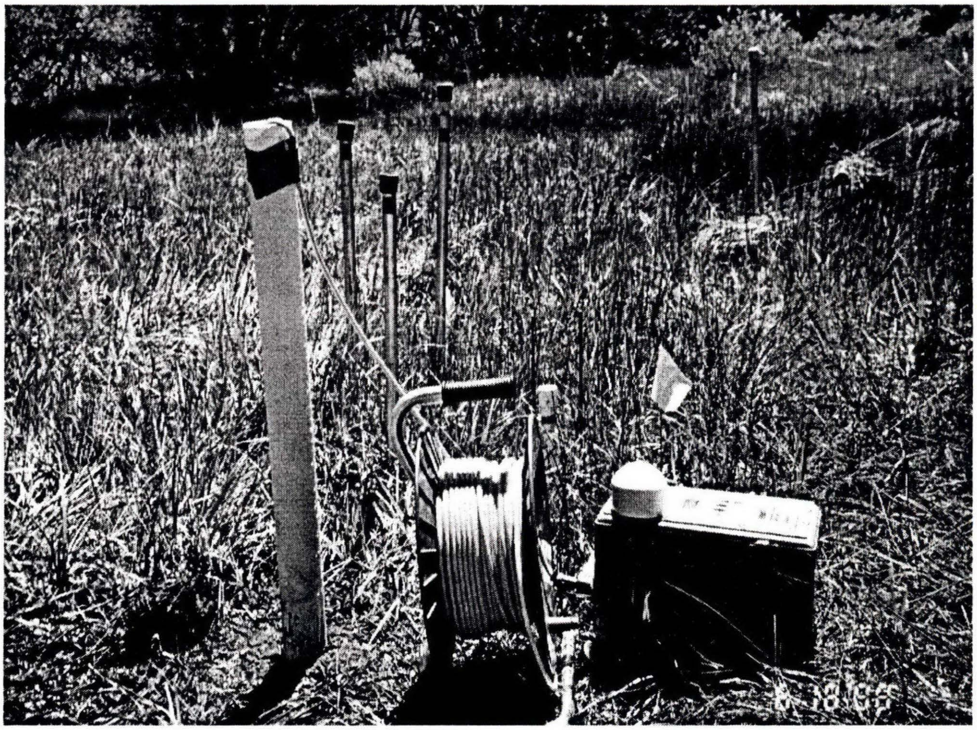


Figure 3. Photograph of nested piezometers and monitoring well at the Big Creek site.

In order to determine possible sources of water to the meadows (deep verses shallow aquifer systems) waters were collected for the analysis of total anions/cations in the summer of 1998. Both pH and temperature were measured in the field prior to filtering and acidification of the samples. These samples were selected from 6 monitoring wells within the Big Creek site using a Teflon® bailer (one monitoring well was dry). In addition, waters from a spring, and five locations along the channel were sampled. Samples were also collected in the summer of 1999 from the monitoring wells within Corral Canyon, and from piezometers and wells within the Big Creek site. Major anion/cation analyses were carried out under the direction of Dr. Paul Lechler at the Nevada Bureau of Mines and Geology. Temperature, pH, dissolved oxygen content, and specific conductivity data were also collected on six other occasions from the Big Creek and Corral Canyon sites from monitoring wells, springs, and the channel reaches using a HydroLab™ downhole Minisonde.

Water samples were collected and analyzed for stable isotopes of carbon and oxygen in the fall of 1998 and summer of 1999 by Dr. Eliot Atekwana and his students from Indiana University-Purdue University at Indianapolis (IUPUI). A modification of the gas evolution extraction technique was used for carbon isotope analysis (Atekwana and Krishnamurthy, 1998). Briefly, 16 x 100 mm glass septum tubes were used. The tubes were prepared for sample collection by dispensing approximately 0.5 ml of 85% phosphoric acid, placing a magnetic stir bar in each tube and evacuating it of air. In the field, 10 ml of water from each sampling location was collected and injected into the prepared septum tube. The water-acid reaction commenced upon sample injection and the evolved CO_2 remained in the closed system until extraction under vacuum. The collected CO_2 was purified cryogenically, the DIC concentration was measured and the $\delta^{13}C_{DIC}$ was determined. For oxygen analysis, water was collected in 20 ml scintillation vials. In the laboratory, 2 ml of water was equilibrated with CO_2 at 25 ^{0}C. The equilibrated CO_2 was extracted under vacuum and analyzed for $\delta^{18}O$. Isotope measurements of both $\delta^{13}C$ and $\delta^{18}O$ were made using a Micromass mass spectrometer. The isotope ratios are reported in the δ notation where:

$$\delta\ (^0/_{00}) = ((R_{sample}/R_{standard}) - 1) \times 10^3$$

R is $^{18}O/^{16}O$ or $^{13}C/^{12}C$. Values are reported relative to SMOW for oxygen and relative to PDB for carbon. Conversion to the standard PDB carbon was made using the NBS-19 standard. DIC concentrations are reported in mg C/L. Routine $\delta^{18}O$, $\delta^{13}C$ and DIC concentration measurements have an overall precision of $0.1^0/_{00}$, $0.1^0/_{00}$ and $1^0/_0$, respectively.

Surface water flow conditions (stream width, depth, velocity, and discharge) were measured along the channel within the Big Creek site on several occasions, all of which correspond to dates during which water level data were obtained from the adjacent piezometers. The initial measurements were obtained with a pygmy or Price meter. However, during the high flow conditions that existed in the spring and early summer, 1998, significant vertical flow gradients prohibited the use of the cup-type velocity meters. Thus, measurements during this interval were collected with an Ott meter designed for higher velocity and more turbulent streams.

We had initially planned on creating a rating curve for one site located near the downstream end of the meadow. Thus, a stilling well was install in the summer, 1997 with the intent of placing an AquaRod™ in the stilling well the following spring. Unfortunately, the high flows in the spring of 1998 were sufficient to erode the channel bed and caused as much as 50 cm of drop in bed elevation, even though the bed was composed of relatively coarse (boulder-sized) material. Channel bed scour inhibited the development of a rating curve. However, Dr. Michael Amacher (USDA, Rocky Mountain Research Station, Logon, Utah) installed a stilling well and AquaRod™ immediately downstream of the Big Creek Site in the summer, 1998, and these data have been made available for use in this study. In addition to the measurement of flow within the channel, surface flows originating from several seeps were periodically determined using volumetric gaging techniques.

The distribution of landforms (e.g., hillslopes, alluvial fans, valley floors, terraces, and channels) and site topography were mapped using the Leica Total Station, and an established X, Y, Z coordinate system that is referenced to the benchmark. In each case, the maps were based on the elevations measured at each of the piezometer and monitoring well locations, and more than 400 additional points. Accuracy of the maps was determined by visual inspection of the cartographic data in the field.

Cross-channel geometry was measured at 20 locations along and downstream of the wet meadow at approximately 20 m intervals. These data were collected by stretching a tape across the channel perpendicular to flow, and measuring the depth of the bankfull channel at selected intervals with a stadia rod. At ten of these sites, grain-size of the channel bed material was measured for 100 clasts over a 25 m reach using a gravelometer and allowed for a determination of the grain-size distribution of the materials by means of a modified Wolman method. Grain size of the bed material at the remaining 10 cross sections was calculated by averaging the results of the data collected at the cross sections immediately up- and downstream of the site. These data were used in conjunction with WinXSPRO to assess potential channel change for a specified set of flow conditions.

RESULTS AND DISCUSSION

Geomorphic Setting of Wet Meadow Ecosystems within the Upland Basins of Central Nevada

Extensive field reconnaissance revealed that upland watersheds within the Toiyabe, Toquima, and Monitor Ranges of central Nevada (Figure 1) exhibit similar valley floor morphologies. They are typically characterized by an integrated stream system that is incised into low-relief, narrow (<150 m wide) valley floors. Interestingly, nearly all of the wet meadow ecosystems are located immediately upvalley of large alluvial fans that have built away from the side valley tributaries (Figure 4). In most cases, these side valley alluvial fans are composed of a single, geomorphic surface (Miller et al., in review). Radial fan profiles measured along this surface demonstrate that during aggradational events, many of these fans extended completely across the valley floor, the deposits impinging on the base of the opposing hillslope (Figure 5). Currently, however, the toe of the fans are truncated by the axial channel which is now confined between hillslope and distal alluvial fan deposits (Figs. 4, 5). Where truncation of the fans has

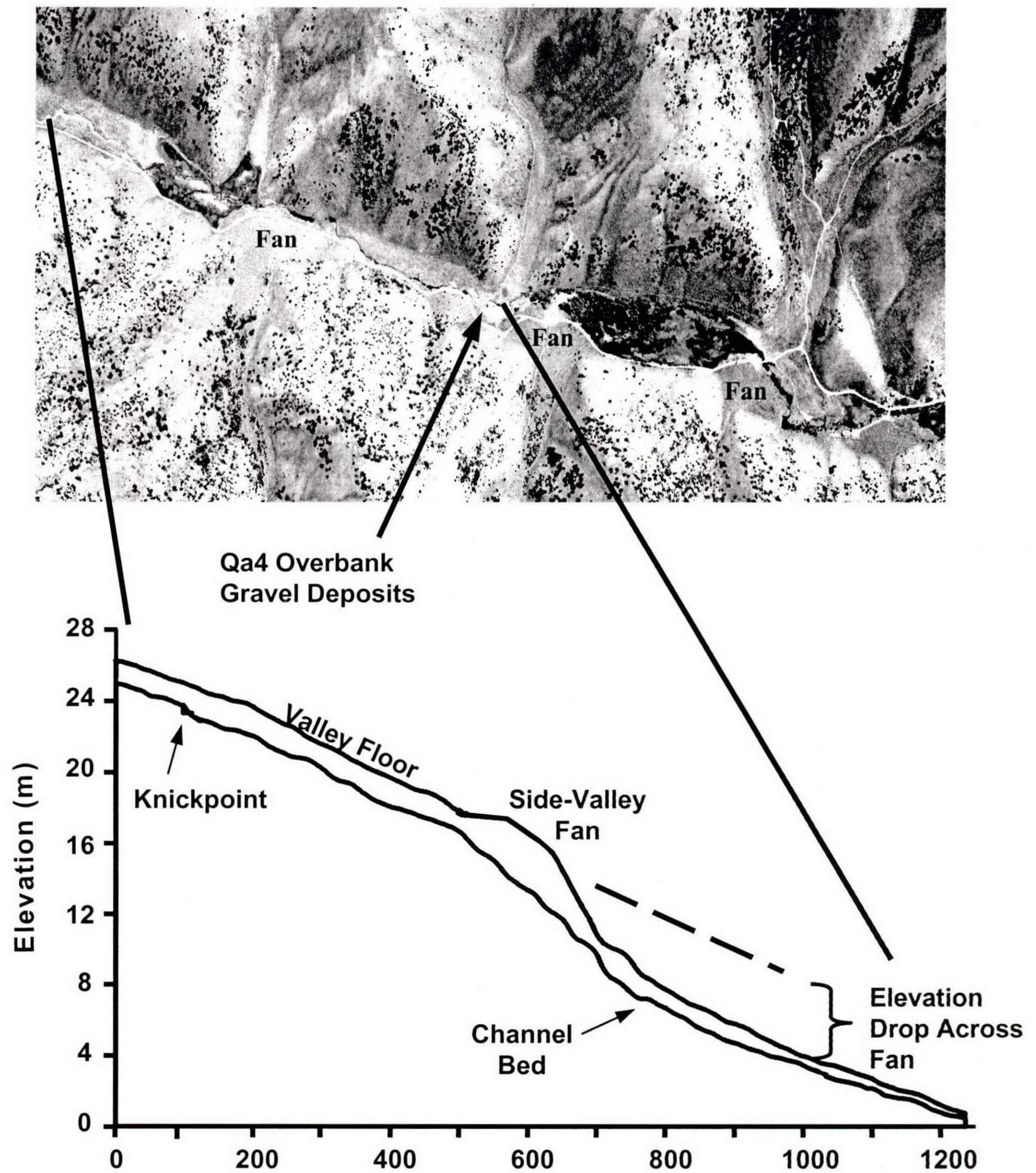


Figure 4. (A) Aerial photograph of side-valley fans in Kingston Canyon showing variations in valley morphology and vegetation types along the valley floor; (B) Longitudinal profile the channel bed and valley floor showing the stepped nature of the valley topography.

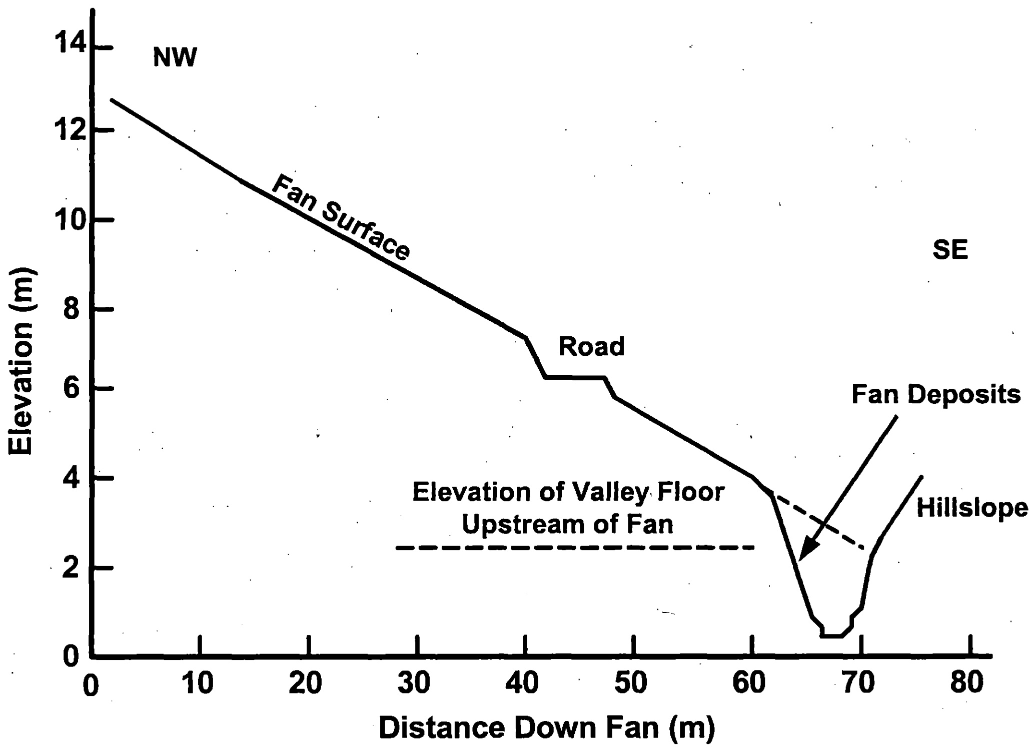


Figure 5. Radial fan profile obtained for the side-valley alluvial fan shown in Figure 2. Prior to truncation of the fan toe, fan deposits appear to have impinged upon the opposing hillslope.

not occurred, the surface of the fan deposits grade smoothly onto the highest surface preserved along the valley floor.

Detailed longitudinal and cross-valley surveys conducted as part of the USDA Ecosystem Management Project illustrate that the alluvial fans can have a significant influence on channel morphology. At many sites, entrenchment tends to be most pronounced at or immediately upstream of the alluvial fans where knickpoints on the order of 0.5 to 2 m in height are developed in fan sediments, or within axial valley alluvium immediately upstream of the fan deposits. Moreover, both the active channel bed and the surface of the valley floor dramatically drop in elevation as the channel traverses the side valley fans, creating a stepped, longitudinal profile. For example, at several locations within Kingston Canyon, the valley floor drops by more than 3 m in elevation as the stream traverses the toe of a fan that constricts the valley width (Figure 4). These abrupt changes in valley floor elevation result in significant variations in channel gradients. Reaches upstream of the fans exhibit relatively low gradients. Slopes increase significantly as the channel traverses the fan deposits, and then systematically decrease farther downstream, forming a concave-up longitudinal profile between successive fan reaches (Figure 4). Thus, the depth of incision, and the gradients of the channel and valley floor, vary along the riparian corridor and are directly related to the geomorphic position of the reach relative to the location of the larger, side valley fan complexes.

The geomorphic relations outlined above are thought to be related to depositional processes that occurred during a significant period of aggradation during the late Holocene. Miller et al. (in review) suggest that prior to approximately 2,000 to 2,500 YBP, an integrated axial channel system existed within the upland basins of central Nevada (Figure 6a). Radial fan profiles demonstrate that shortly thereafter, the flow of water and sediment downvalley was temporarily blocked by the episodic deposition of debris on the large side valley fans (Figure 6b). These fan deposits were eventually breached and reworked by the axial channel system, resulting in a re-integration of the axial channel. The net product of this process was apparently enhanced deposition of sediment upstream of the side valley fans, stepped longitudinal profiles, and significant spatial variations in channel gradients.

The morphologic variations described above occur at the Corral Canyon site examined in this investigation, and may be enhanced by the protrusion of a bedrock outcrop from the valley margins at the downstream end of the wet meadow (Figs. 7, 8). Of particularly interest is the occurrence of a significant headcut (>1.5 m in height) at the downstream end of the meadow (just below the valley constriction), and the initiation of an incised channel downstream of this point. Upstream of the headcut, an integrated axial channel system does not exist (Figure 8). Furthermore, valley floor gradients increase dramatically downstream of the constriction, and coincide with the position of the headcut, suggesting that valley incision is related, at least in part, to changes in valley morphology (Figure 7).

Changes in channel gradients, and a stepped, longitudinal profile, do not occur at all of the alluvial fans found within the upland watersheds. This is clearly illustrated at the Big Creek site where alluvial fans constrict the valley at the downstream end of the wet meadow (Figures 2b, 9), but significant changes in channel gradients do not occur (Figure 10). Germanoski et al. (1999) suggest that at these sites, either (1) fan aggradation did not create significant downstream

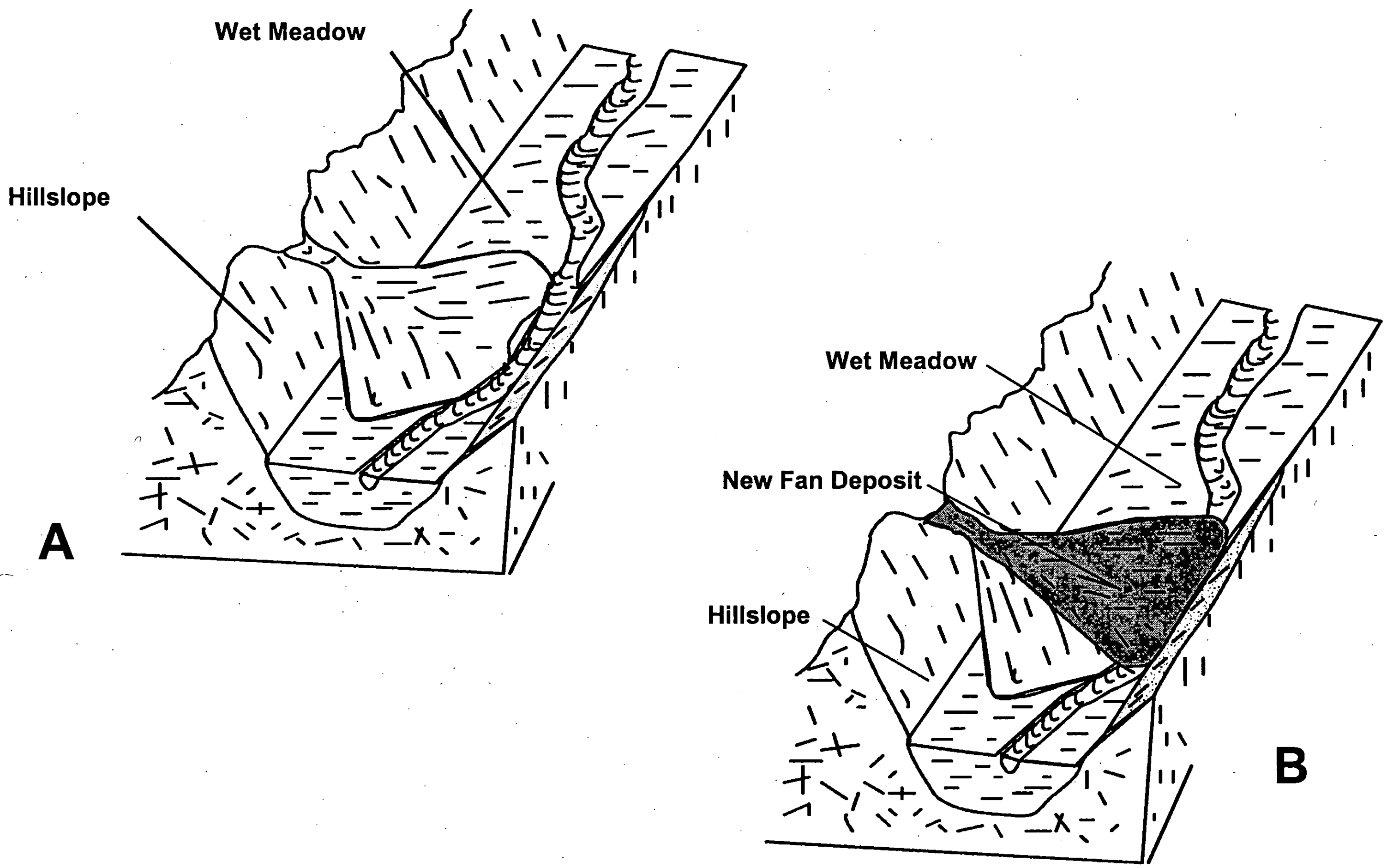


Figure 6. Schematic diagram illustrating the impact of side valley fans on sediment transport and deposition. Fan building is thought to have temporally blocked the axial channel increasing deposition upvalley of the fans, a process that is likely to have produced a stepped longitudinal profile. At some point, the axial channel would have breached the fan deposits, reintegrating upstream and downstream reaches.

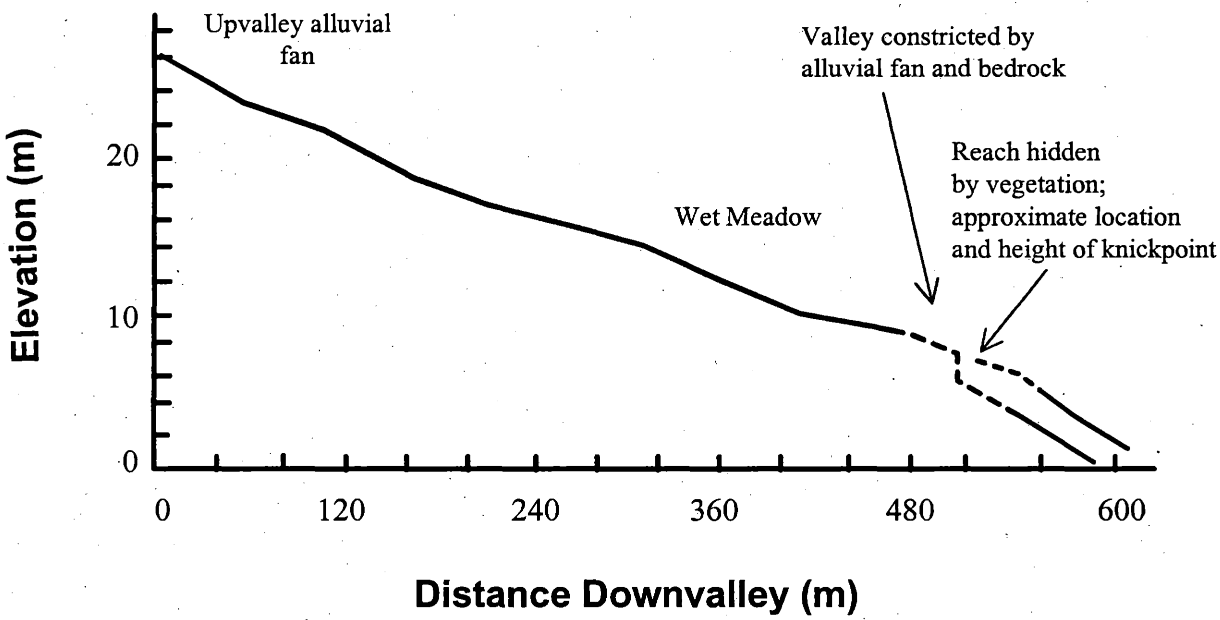


Figure 7. Longitudinal profile along the valley axis of the Corral Canyon site.

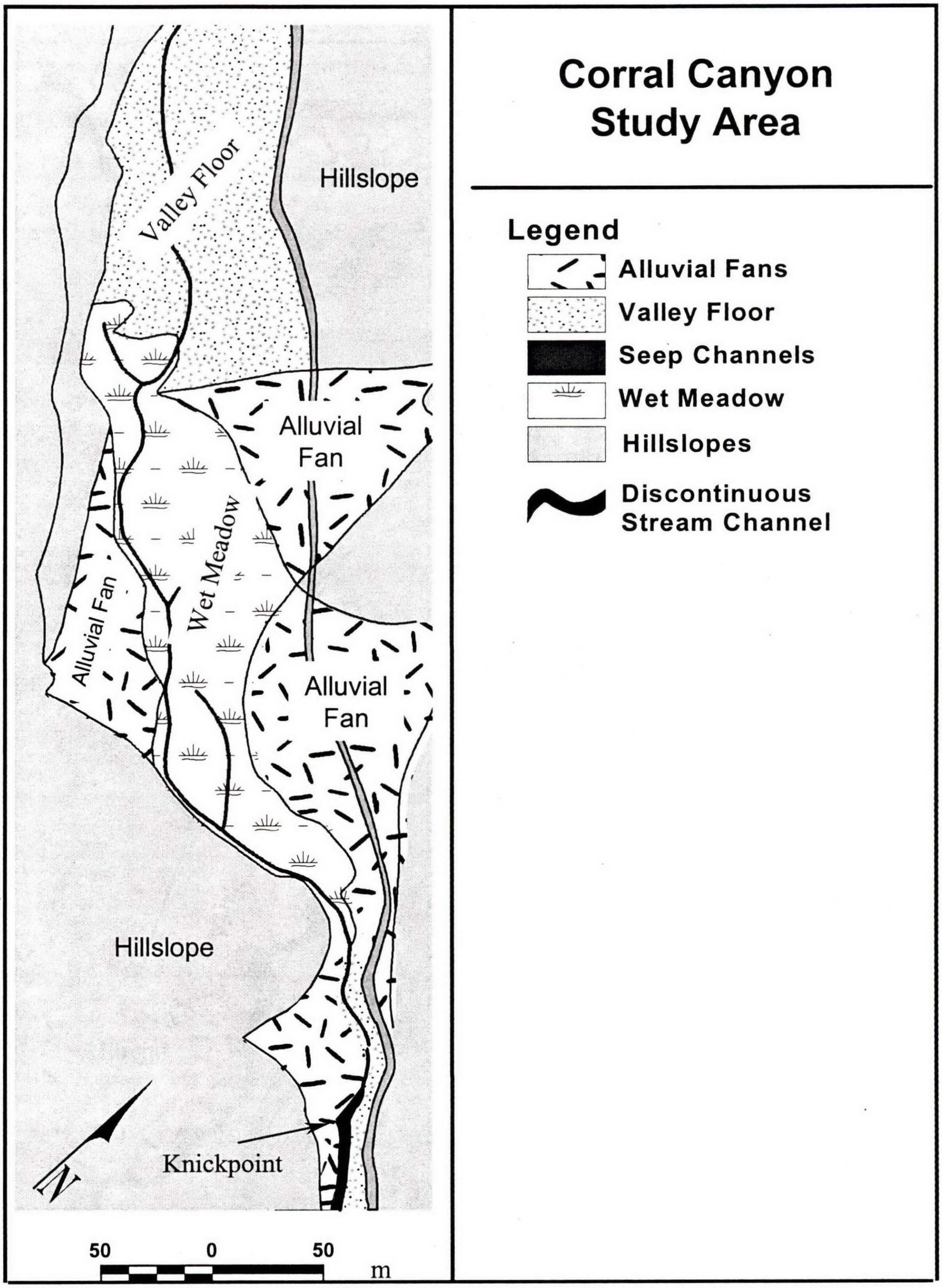


Figure 8. Landform map of the Corral Canyon Site. Stream channel is characterized by Disontinuous reaches. Channel is well integrated and incised below valley floor down-stream of knickpoint.

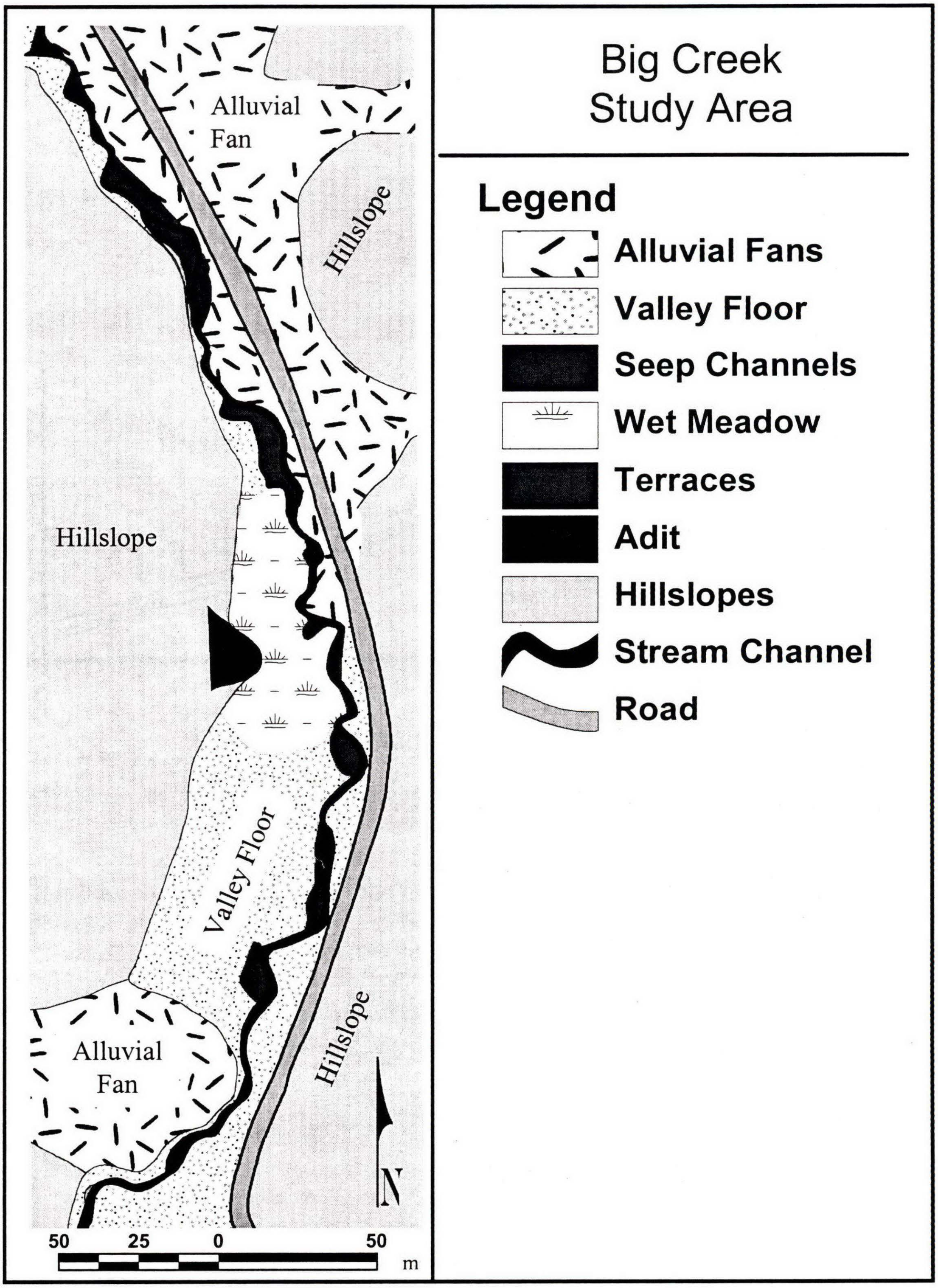


Figure 9. Landform map of the Big Creek site. Flow is from toward the north.

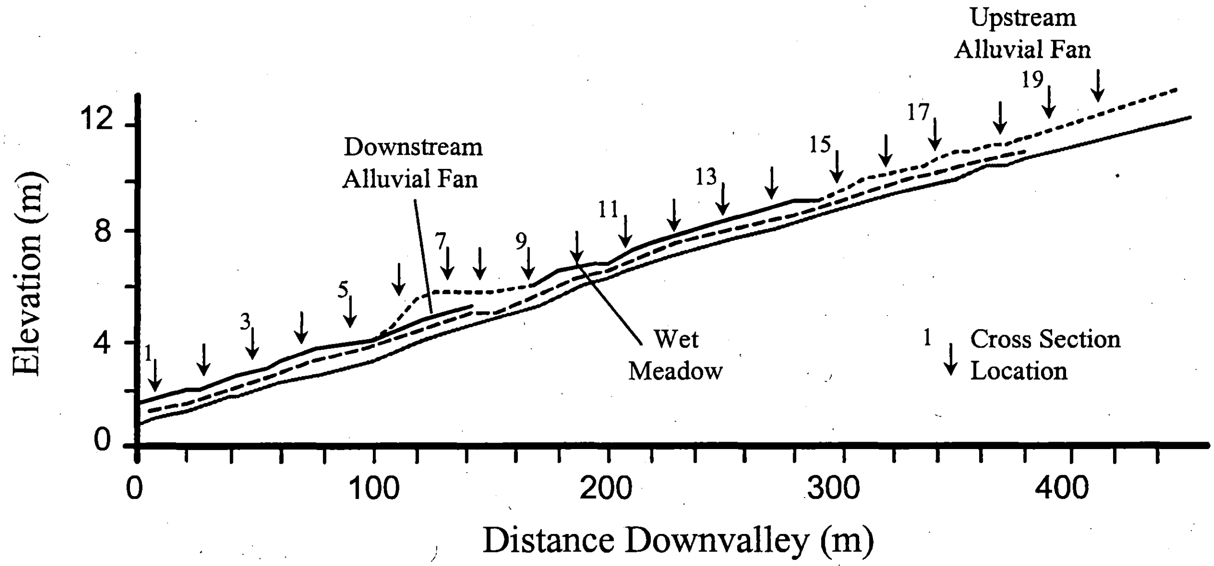


Figure 10. Longitudinal profiles along valley floor, terraces, and channel bed of Big Creek within the study area.

variations in channel gradients, or (2) channel entrenchment has progressed through the fan deposits, erasing any significant irregularity in channel gradients that may have been imposed on the system during fan building. Although the wet meadows exist where stepped, longitudinal profiles do and do not occur, their occurrence upstream of side valley alluvial fans suggests that the meadows are genetically linked in some fashion to the fan deposits.

Sedimentology and Stratigraphy of Alluvial Deposits within the Wet Meadow Study Areas

The Big Creek Site

In conjunction with the Ecosystem Management Project, the mid- to late Holocene valley fill stratigraphy has been documented for several upland basins in central Nevada including the San Juan and Cottonwood Creek basins in the Toiyabe Range, the Stoneberger Creek basin within the Toquima Range, and the Barley Creek basin within the Monitor Range (Figure 1). Similar stratigraphic relations were identified for each of these basins (Figure 11; Miller et al., in review). Moreover, field reconnaissance suggests that the valley fill stratigraphy within the Corral Canyon and Big Creek sites examined in this study is comparable to that observed within these other watersheds. Thus, attempts were made here to link the alluvial deposits within wet meadows of the Big Creek and Corral Canyon study sites to the regional stratigraphy of Miller et al. (in review) in order to: (1) increase our understanding of the sedimentology and stratigraphy of the materials found within the study areas, and (2) reduce the confusion that may otherwise develop concerning stratigraphic nomenclature.

The wet meadow complex within the Big Creek study site is bound, both upstream and downstream, by side valley alluvial fans (Figure 9). Exposures of the fan deposits were limited at the site, although an exposure 2.5 m high was examined at the downstream end of the meadow. The exposed fan materials were interpreted to represent Qf2 deposits (Figure 11) consisting of weakly bedded, clast supported gravels containing a loamy, medium to course sand matrix. Failed attempts to install hand-augured monitoring wells, and the difficulties of installing the piezometers, demonstrate that the upstream fan (Figure 9) consists of similar materials. Geulph infiltrometer tests conducted on fan surfaces demonstrated that the deposits exhibited relatively high hydraulic conductivities, ranging from 6.5×10^{-3} to 8.99×10^{-3} cm/s (Table 1). Based on the regional stratigraphic relations, it is likely that Qf2 deposits interfinger with Qa2 deposits along the distal margins of the fans (Figures 9, 11). Exposures of Qa2 are not present at the site. However, Qa2 deposits within other watersheds of the Toiyabe Range consists of both a fine- and coarse-grained facies (Miller et al., in review). The fine-grained facies ($Qa2_f$) is characterized by silty clay loam textures which contain <10-15 % gravel dispersed throughout the material. The unit also contains 1-10 cm thick, discontinuous layers of dark brown to black silt enriched with charcoal. The coarse-grained facies ($Qa2_g$) is dominated by a clast supported gravel with a fine sand to sandy loam matrix. This facies typically occurs as 0.5-2 m long lenses within the fine-grained facies. The grain size of both facies was observed to decrease away from side valley alluvial fans.

The surface materials within the wet meadow complex were interpreted to consist almost exclusively of Qa4 deposits, although a terrace surface located immediately adjacent to the channel along several reaches may be underlain at depth by Qa3. Numerous attempts to obtain lengthy sediment cores with both the Livingston Coring device and a split-spoon sampler

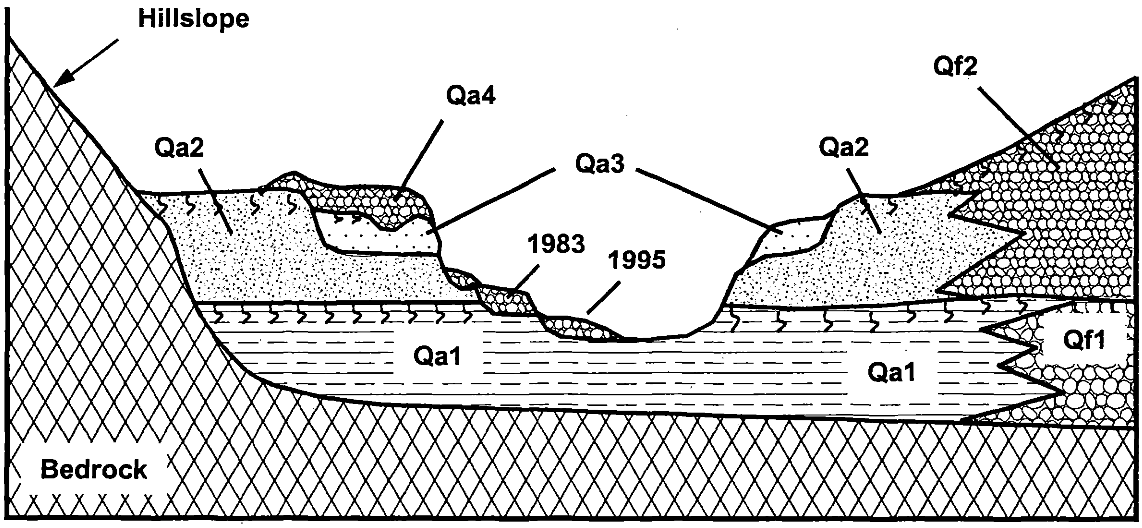


Figure 11. Schematic diagram of mid- to late Holocene stratigraphy within the study basins.

attached to a hammer driver failed as gravel sized materials were encountered at depth. As a result, intact Qa4 materials were obtained from only the upper 0.4 m of the valley fill, and the thickness of Qa4 at the site could not be precisely determined. However, auger cuttings examined while installing the monitoring wells suggest that Qa4 may exceed 0.5 to 1 m in thickness, and may be bound at depth by a more silt and clay rich soil associated with the surface of Qa2. This is supported by a sediment core exceeding 4 m in length obtained from a wet meadow in Kingston Canyon located on the opposing side of the Toiyabe Range (Figure 12). The basal materials within this core are composed of Qa2 materials, as would be expected from regional observations of the valley fill, although the soil in Qa2 at this site has apparently been truncate by erosion. Regardless of whether the finer-materials correspond to Qa2 deposits, a more indurated, finer-grained unit was noted while installing the piezometers at the Big Creek site, and is thought to exist semi-continuously beneath the wet-to-mesic meadow complex at a depth of between 0.5 and 1 m below the surface.

The upper 0 to 5 cm of Qa4 within the wet-to-mesic meadow consists of a dense mat of roots and undecomposed plant materials forming a peat-like deposit. Immediately underlying the peat-like deposits are dark-colored, organic rich sediments that contain higher percentages of mineral matter, and which are dominated by fine-grained sediments. Falling head permeameter data collected for cores through these materials range from 1.48×10^{-5} to 2.31×10^{-2} cm/s (Table 1).

Table 1

Big Creek Hydraulic Conductivity Measurements

Site Location	Material	Method	Conductivity
Center of upper fan	Alluvial fan	Guelph permeameter	8.99×10^{-03}
Tail of upper fan	Alluvial fan	Guelph permeameter	6.55×10^{-03}
Wet meadow	Peat core BC-1	Falling head permeameter	2.31×10^{-03}
Wet meadow	Peat core BC-2	Falling head permeameter	6.91×10^{-02}
Wet meadow	Peat core BC-3	Falling head permeameter	1.30×10^{-02}
Wet meadow	Peat core BC-4	Falling head permeameter	1.48×10^{-05}
MW-2	Alluvial/fluvial	Slug Test	7.34×10^{-02}
MW-3	Peat	Slug Test	5.40×10^{-02}
MW-4	Peat	Slug Test	3.90×10^{-03}
MW-26	Alluvial	Slug Test	3.40×10^{-02}
MW-32	Alluvial	Slug Test	2.70×10^{-02}

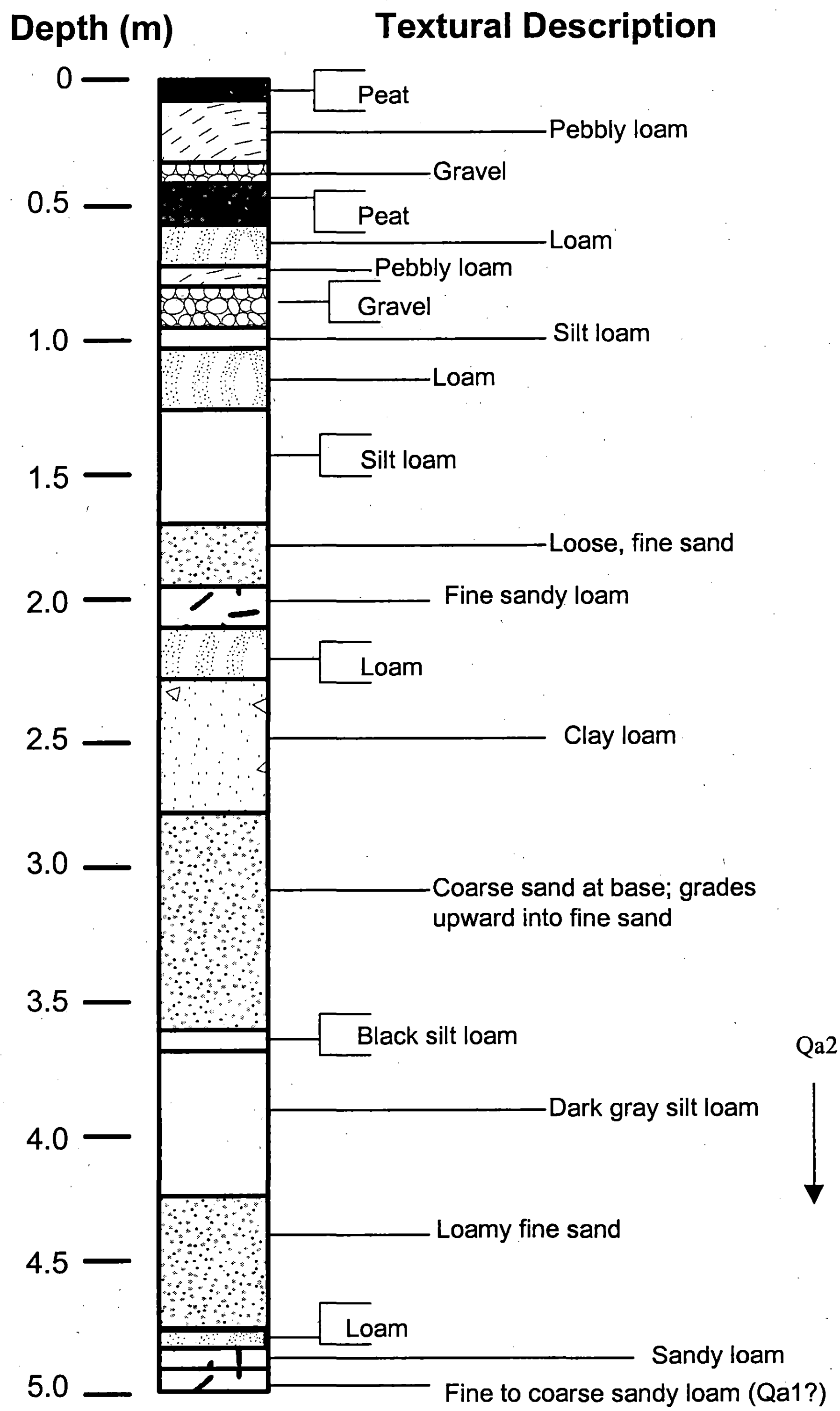


Figure 12. Stratigraphic data extracted from Core A of a wet meadow complex from Kingston Canyon.

The sedimentology of Qa4 deposits at depths below the materials observed within the cores taken at the Big Creek site (i.e., below 0.4 m) is more difficult to ascertain. However, at most other sites where exposures of Qa4 have been observed, the deposits are dominated by horizontally bedded sands, silts and clays, some of which contain abundant plant macrofossils and roots which form thin (<10 cm thick) peat-like layers. Locally, Qa4 contains interbedded paleochannel fills, consisting of a wide-range of sediment sizes, that are inset into (and abut) the generally finer-grained valley fill. It is not uncommon for these paleochannel fills to contain lenses of coarse-grained, clast-supported gravel that completely fills the channel and has spilled onto the valley floor. Radiocarbon analyses of charcoal and other organic materials found within the paleochannel fills suggest that the cut and fill processes associated with Qa4 began at least 440±50 YBP, and field reconnaissance following the 1995 event shows that it is still locally occurring today (Miller et al., in review).

Miller et al. (in review) suggest that Qa4 results from (1) the infilling of the axial channel upstream of the side valley alluvial fans, a process that periodically forced water and gravel bed material over the valley floor, and (2) the subsequent cutting of a new channel through the wet meadow complex. Viewed from this perspective, Qa4 is the product of channel avulsion initiated by aggradation upstream of the side valley fans. It is not entirely clear why aggradation occurs in these locations, but it may be related to the rapid introduction of gravel sized materials to the channel from upstream sources, and a systematic decrease in gradients as the stream approaches the alluvial fans which inhibit the downstream movement of the coarser-grained sediments. The coarsest material found in Qa4 is located along the axis of the valley and is presumably associated with filled paleochannels, and other coarse-grained deposits that spilled onto the valley floor. Finer-grained sediment is apparently transported to the valley margins during floods where it was deposited by slower moving waters. The net result of these erosional and depositional processes is a spatially variable, and highly complex alluvial fill stratigraphy characterized by abrupt changes in sediment size, both vertically and laterally, immediately upstream of the side valley fans and in the vicinity of the wet-to-mesic meadow complexes.

The Corral Canyon Site

The field site within Corral Canyon is also bound upstream and downstream by alluvial fan deposits (Figure 8). Unfortunately, surface exposures of these materials do not exist within the area. However, on the basis of regional data, and the nature of the fan surfaces, we believe that the upper fan materials correspond to Qf2 deposits that consist of clast-supported gravels that house a loamy, sand matrix. The occurrence of gravel at depth is supported by the difficulties encountered while installing the piezometers within the alluvial fans. On a number of occasions the electrical conduit was bent as the drive point struck a large clast, and it was necessary to find a new location for piezometer installation.

Several cores exceeding 3 m in thickness were obtained from downvalley reaches of the field site. The sedimentology/stratigraphy of the most complete core is shown in Figure 13. Correlation of the observed stratigraphic units with the regional stratigraphy of Miller et al. (in review) proved problematic for two reasons. First, the materials within the core lacked well defined weathering zones (soils) or erosional boundaries that would indicate changes in

depositional units. Second, dark-colored, charcoal layers, which are one of the diagnostic features of unit Qa2, were not observed within the core. Although it is not possible to relate the valley fill, as observed within the cores, to the regional stratigraphy, the general nature of the valley fill deposits can be described for the site.

Of importance to the local groundwater flow system is the fact that a general change in the sedimentologic nature of the materials occurs at approximately 1 m in depth. The upper deposits consist of relatively fine-grained sediments (silts and loams), interbedded with peaty deposits (Figure 13). Loose sand deposits are scare and relatively thin. In Core C, for example, only one fine sand unit occurs within the upper 1 m of the valley fill (Figure 13). In contrast, from 1 to 4 m in depth, the deposits are dominated by loose sand beds, which are interlayered by either loam or silt rich materials (Figure 13). We suspect that the sediment-size within the deposits becomes coarser grained as the distance to the alluvial fans decreases.

Interactions of the Surface and Groundwater Flow Systems

The Big Creek Site

In order to observe patterns in surface and subsurface hydrology and the interactions between hydrologic systems at the Big Creek field site, the site was instrumented with 54 piezometers, 7 monitoring wells, and a stilling well. The piezometers and monitoring wells provide a means for measuring the depth to the water table across the site and allow the calculation of the water table elevation from survey data. The stilling well provides a stream stage monitoring location. The monitoring wells also serve as locations for collecting water quality samples, measuring in-situ water quality parameters, and evaluating hydraulic conductivity using slug test analyses. The distribution of piezometers and monitoring wells at the Big Creek site is presented in Figure 14. Although high flows during spring 1998 rendered the stilling well location unusable, stage data were collected downstream of the site for the 1998 field season by Dr. Michael Amacher (USDA Forest Service).

Figure 15 provides a summary of the depth to the water table (average depth ± 1 standard deviation) during the 1997-1999 field seasons for piezometers located in the upper (southern), mid, and lower (northern) regions of the site. The upper region corresponds to the sagebrush and dry meadow vegetation zones reported by Castelli (1999). The mid and lower regions correspond to the mesic and wet meadow areas (Castelli, 1999). Monthly precipitation at the USDA/NRCS Big Creek Summit weather station also is given in Figure 15. Although depth to water data were not collected throughout the entire year due to difficulties in accessing the site during the winter season, the piezometer data provide a glimpse of the hydroperiod for these three regions. The hydroperiod is the seasonal pattern of the water level, a hydrologic signature, of a wetland (Mitsch and Gosselink, 1993). The depth to water is greatest in the upper (southern) end of the Big Creek site and water depths decrease as one moves towards the lower (northern) end of the site. Water levels tend to be at their highest following the annual snowmelt and spring rains and the depths to water across the site decrease throughout the remainder of the year. The annual change in water table depths is greatest in the upper region and least in the lower region. Variation in water table depths follow a similar pattern (as depicted by standard deviation results).

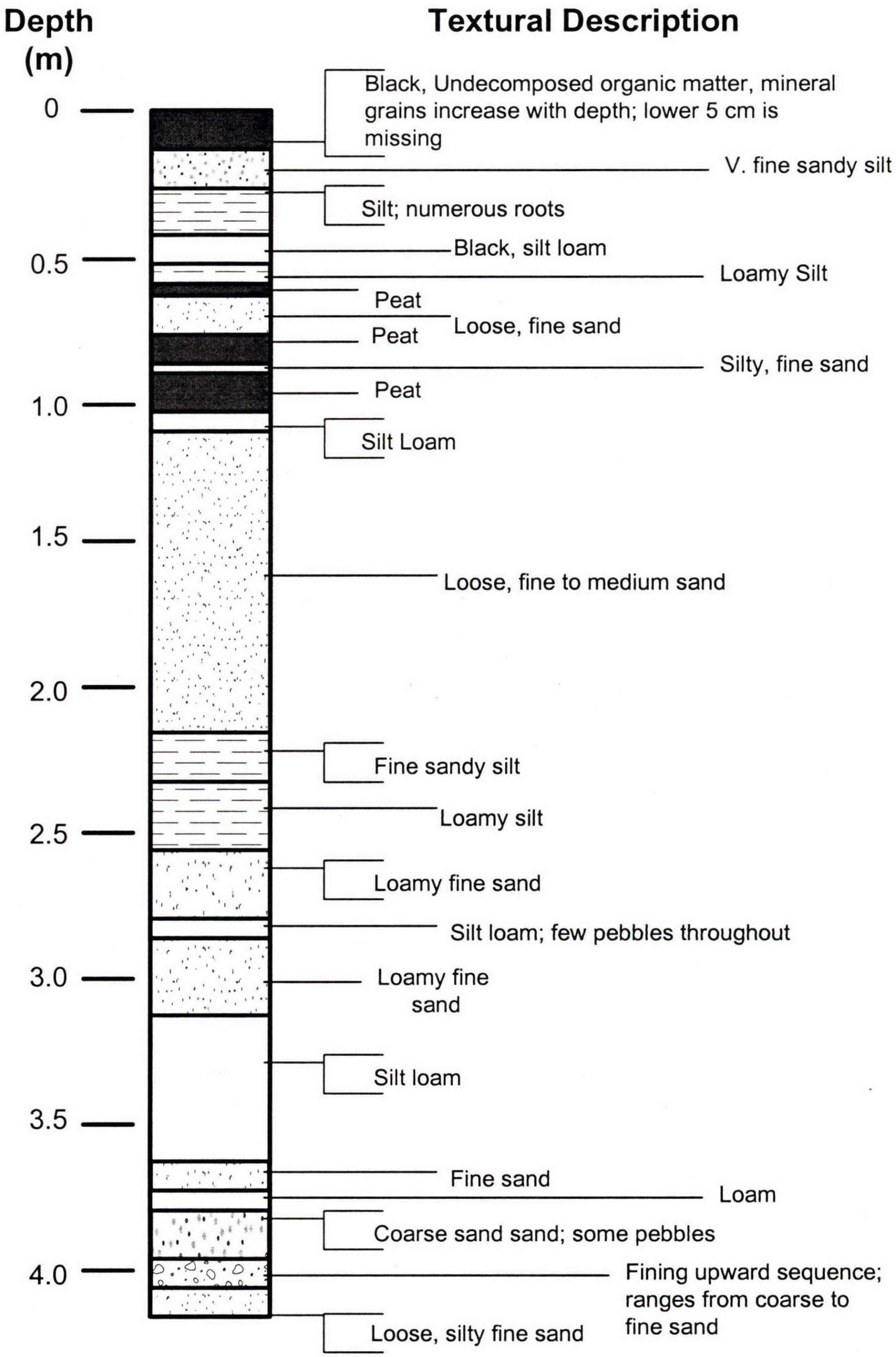


Figure 13. Stratigraphic data obtained from a core extracted from Core C in Corral Canyon.

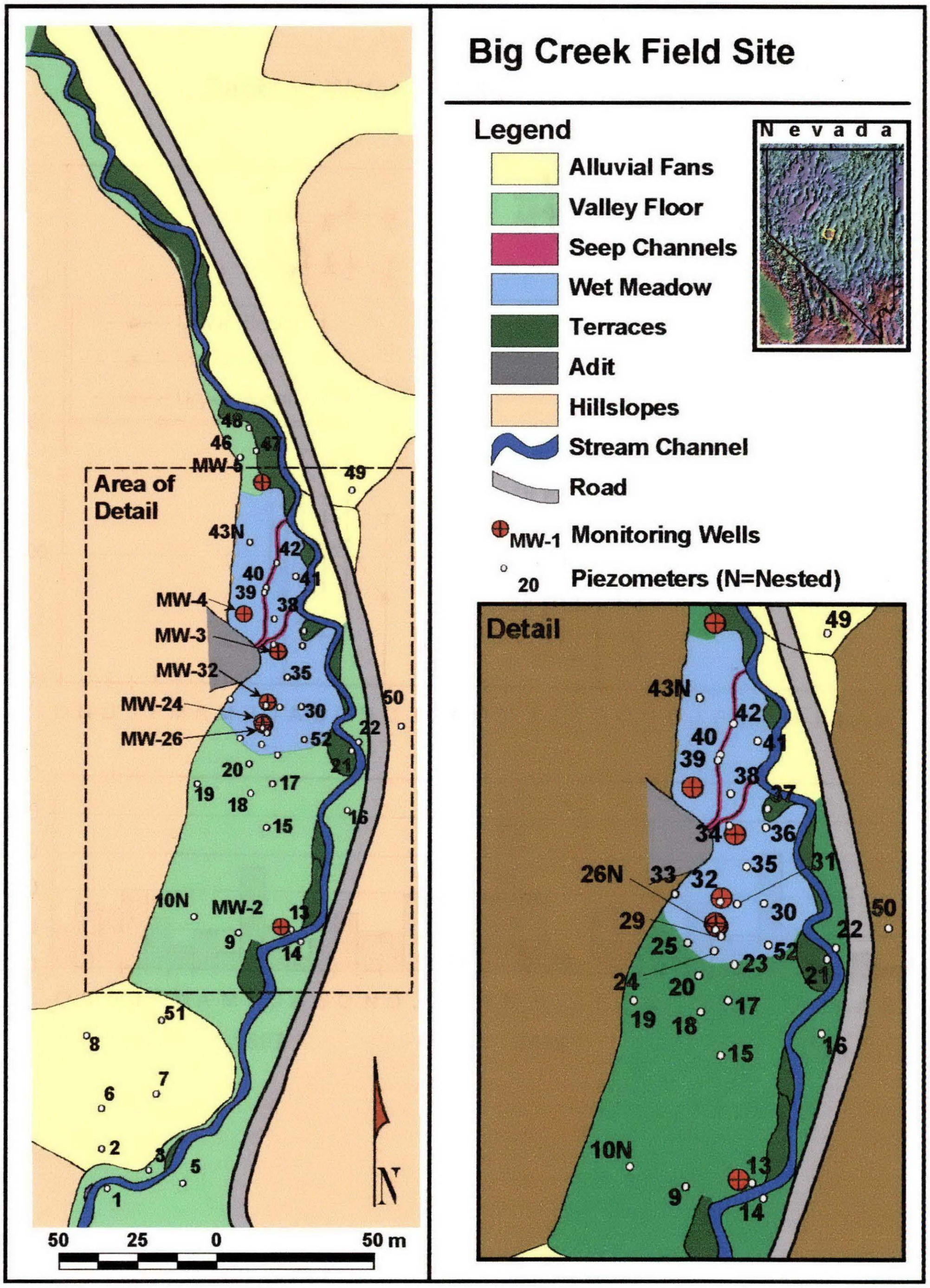


Figure 14. Piezometer and monitoring well locations at Big Creek site.

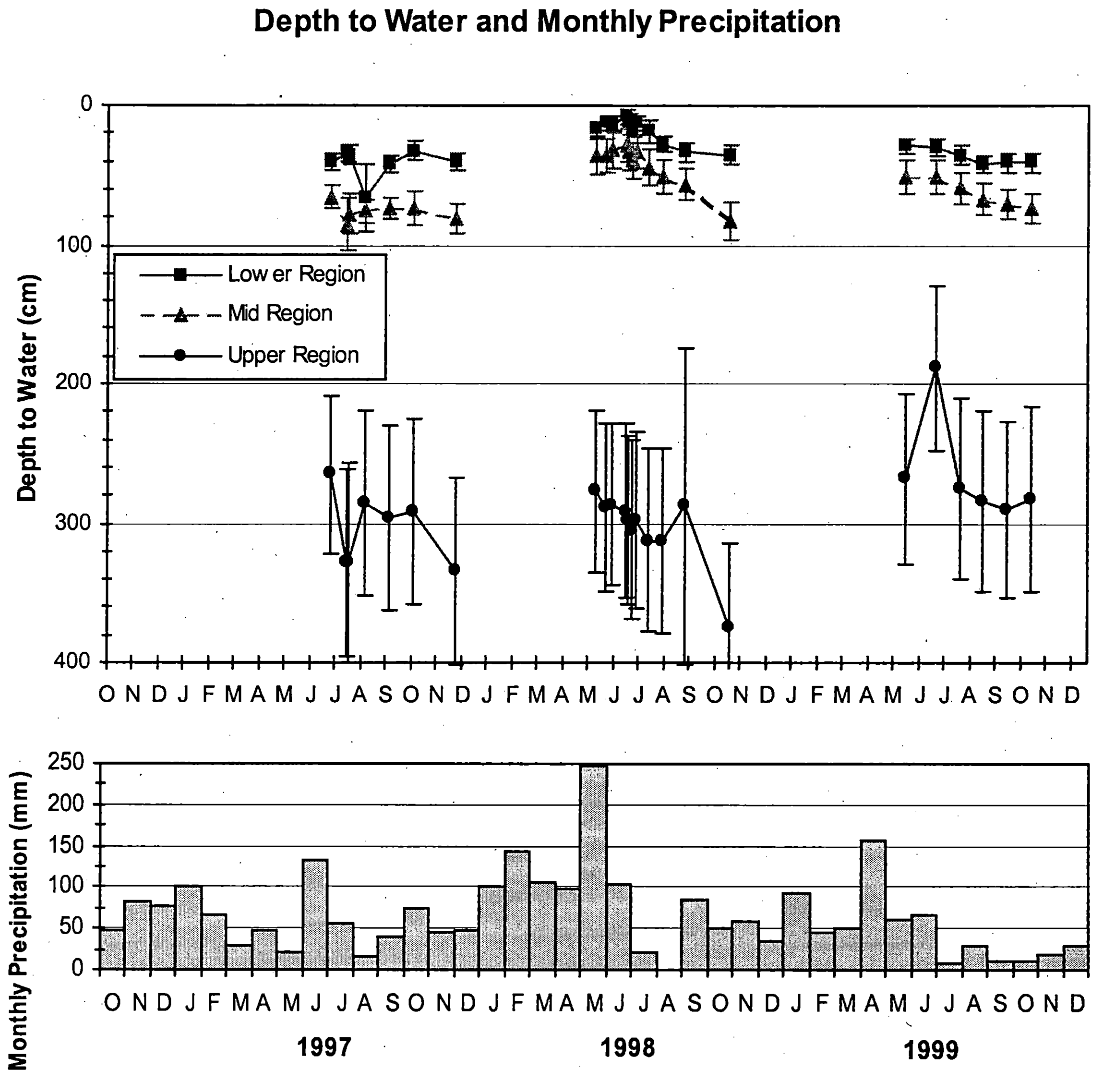


Figure 15. Average depth to water (± 1 standard deviation) in upper, mid, and lower regions of the Big Creek site and monthly precipitation data collected at USDA/NRCS Big Creek summit weather station for 1997-1999.

Depth to water, daily precipitation, and Big Creek stage data for 1998 are presented in Figure 16. Note that both surface water and groundwater levels are highest following the snowmelt and heavy spring rains. Surface water and groundwater levels drop during the remainder of the year except for a September 1998 storm event. During this storm event water levels in the stream and in the piezometers located in the upper region of the site increased while the water levels in the other piezometers continued to decrease. This suggests that groundwater in the upper region of the Big Creek site is influenced by short-term precipitation events that also increase stream stage and/or increase groundwater input originating from the alluvial fan deposits.

To illustrate groundwater flow patterns at the Big Creek site during wet and dry seasons, water level elevation data for wet and the dry season monitoring events have been contoured using the SURFER™ software package (Golden Software, 1995). Figure 17 presents the water table surface at the Big Creek site during a wet season monitoring event (data were collected 26 June 1998). The contours represent lines of equal water surface elevation (a.k.a. equipotentials) relative to a temporary datum and groundwater flows from higher to lower values, perpendicular to the equipotentials. Groundwater flow in the upper (southernmost) portion of the site is influenced by Big Creek and the alluvial fan. The water table surface indicates that the upper reach of Big Creek is a losing stream, providing water to the groundwater system. The alluvial fan deposits in this area also provide a subsurface source of water input to the site. Groundwater moves downgradient, to the north, through the midsection of the site. Big Creek then becomes a gaining stream, receiving baseflow from the subsurface, as it traverses the mid to lower reaches of the site as indicated by the concave pattern of equipotential lines (converging groundwater flow). Another interesting feature is the area of groundwater discharge near the adit (Figure 17). Equipotential lines are deflected around this feature and groundwater seeps emanate nearby.

Similar groundwater patterns at the Big Creek site are evident during the dry season (Figure 18, data collected 18 August 1997). Input from the stream and the alluvial fan deposits still occur, but the depth to water has increased and the hydraulic gradient has decreased. Groundwater flows downvalley where the depth to water is slightly greater through the mid section during the dry season. Groundwater discharge still occurs, however, along the lower reaches of Big Creek, and the groundwater discharge feature in the vicinity of the adit is slightly more pronounced during the dry season.

To better illustrate groundwater gradients and differences in groundwater levels between wet and dry seasons, water table profiles have been produced for various cross sections through the site (Figures 19 and 20A-D). Figure 19 is a key to the location of the water table profiles illustrated in Figure 20A-D. The data used to create these profiles are the same used to generate Figures 17 and 18. Figure 20A is a south to north, longitudinal water table profile along the axial valley. As discussed previously, groundwater flows from south to north through the site. The wet season water table occurs at a shallower depth throughout the site compared to dry season water table and the difference in depth between these two monitoring events is greatest in the upper (southern) region and least in the lower region near groundwater discharge zones. Profile B-B' (Figure 20B), a west to east cross section across the upper region of the site, illustrates marked differences between wet and dry season groundwater flow patterns. During the wet season, Big Creek is a losing stream, recharging the subsurface system. Even though the stage of

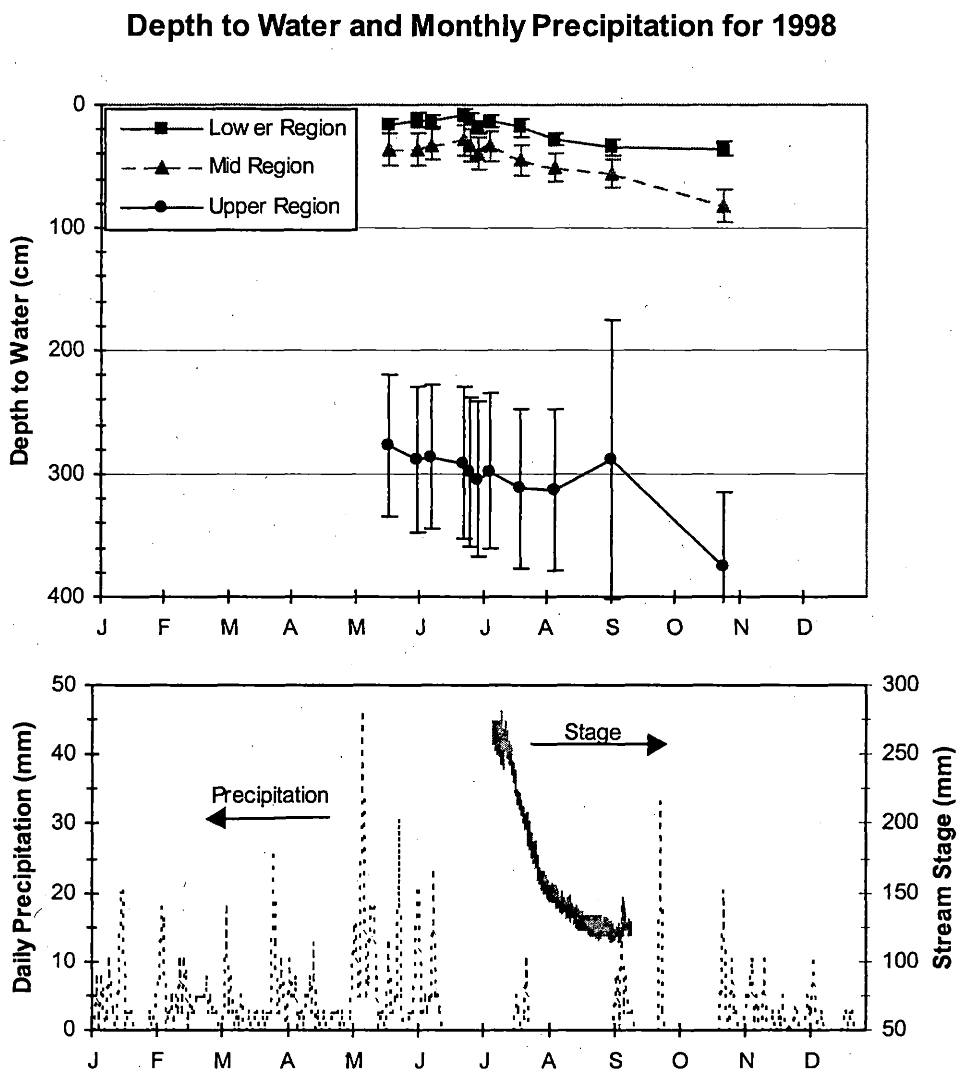


Figure 16. Average depth to water (± 1 standard deviation) in upper, mid, and lower regions of Big Creek site, daily precipitation (data from USDA/NRCS Big Creek summit station), and Big Creek stage (data from Dr. M. Amacher, USDA Forest Service) for 1998.

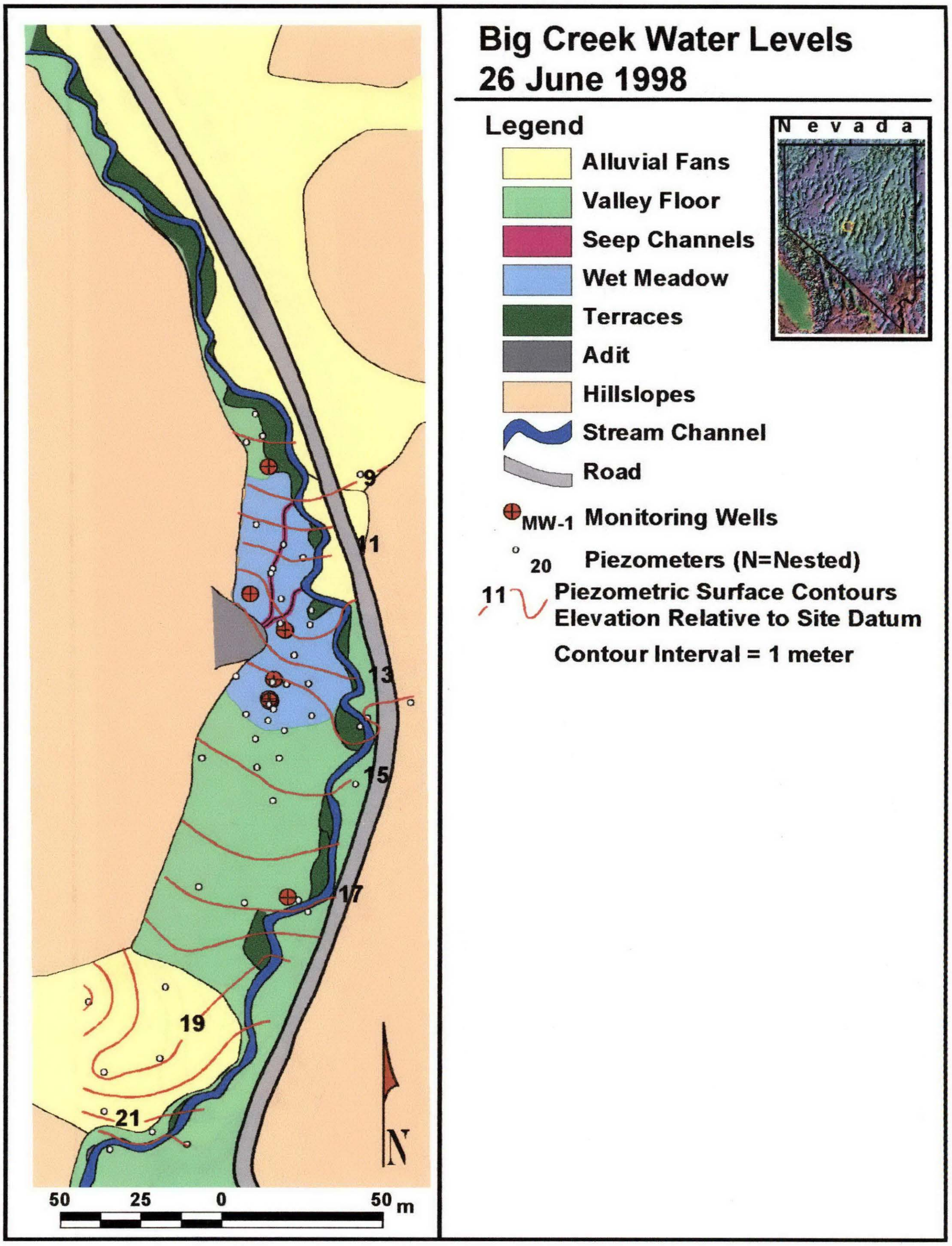


Figure 17. Big Creek water table surface for wet season monitoring event (26 June, 1998).

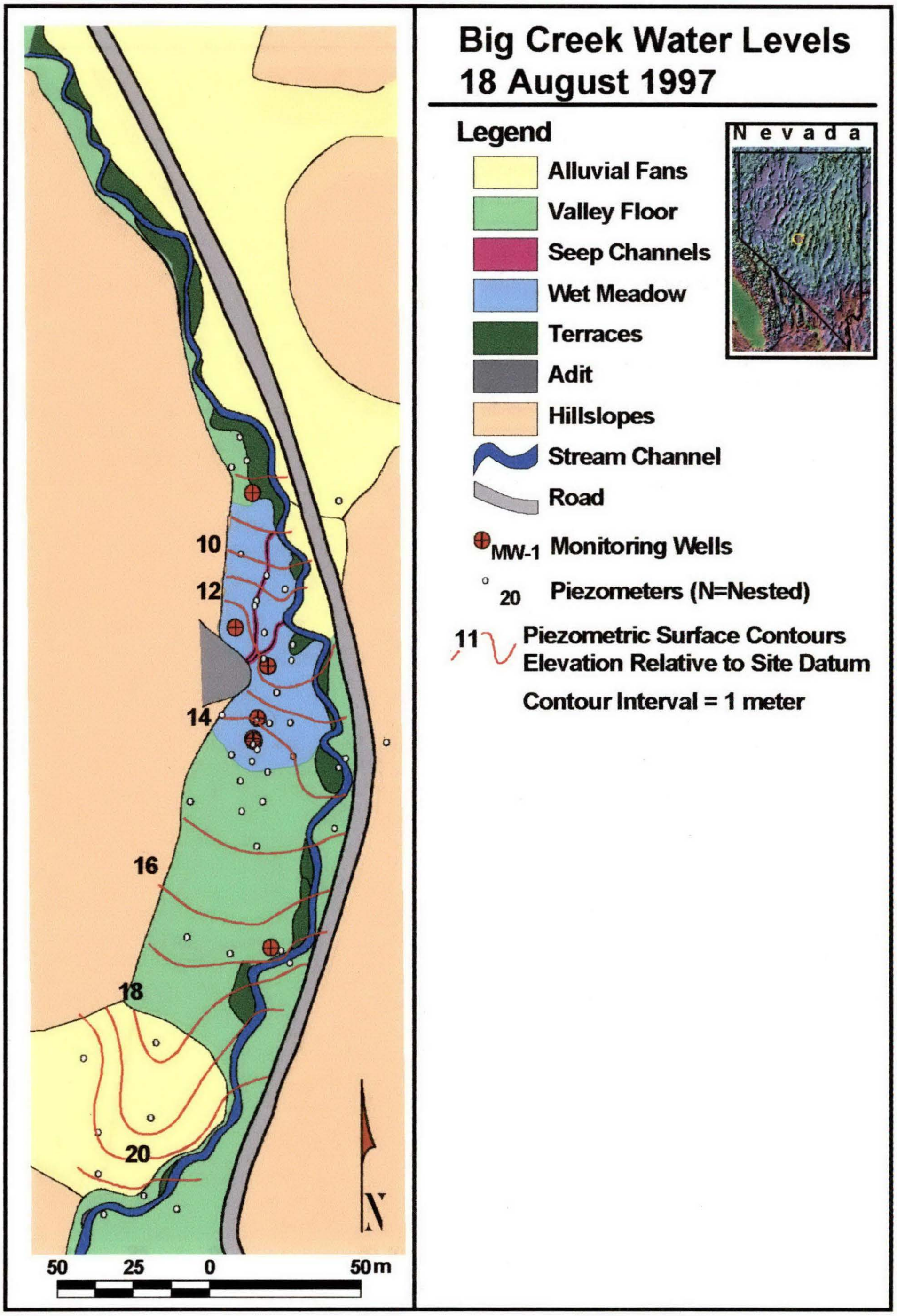


Figure 18. Big Creek water table surface for dry season monitoring event (18 August, 1997).

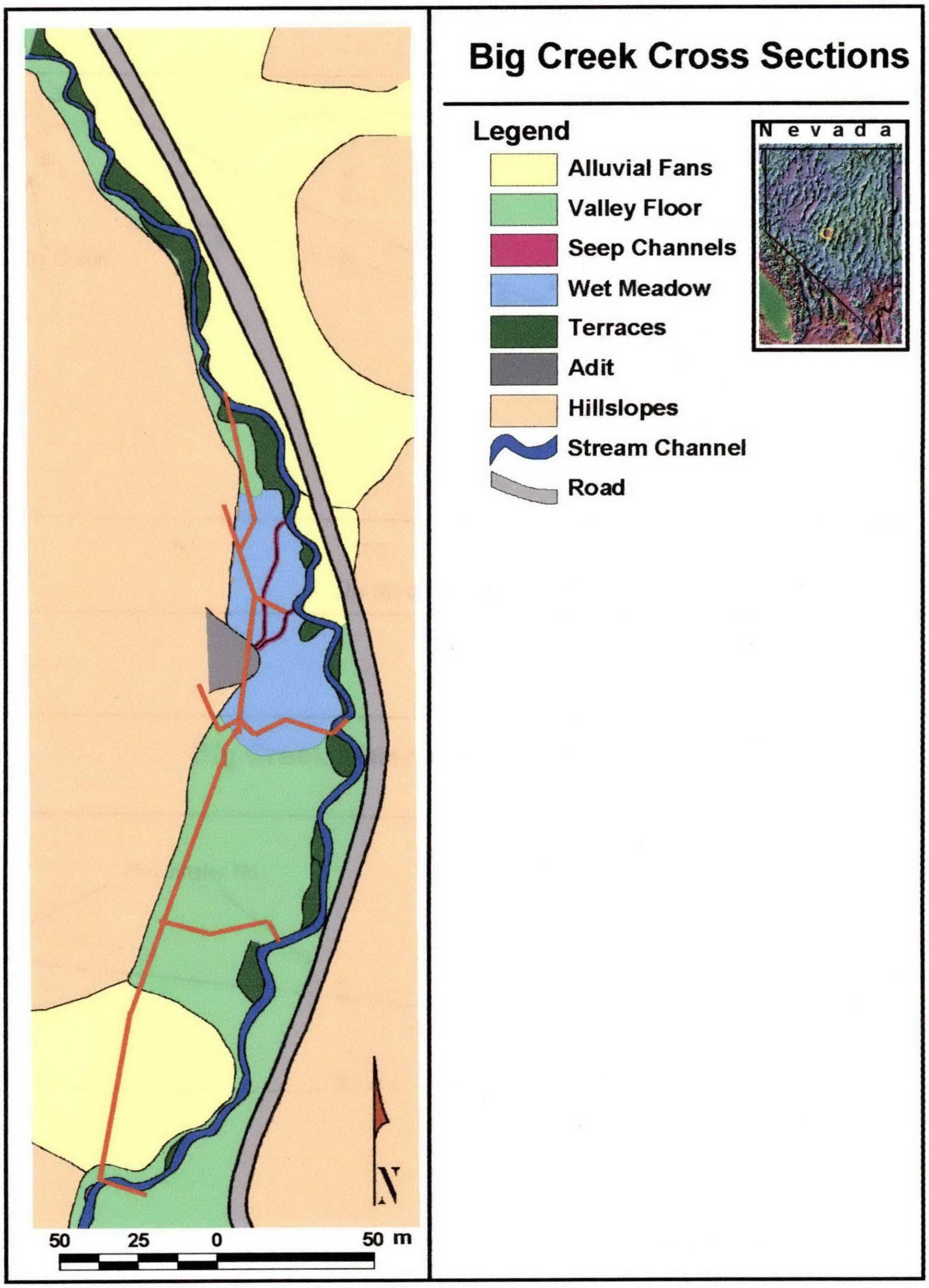
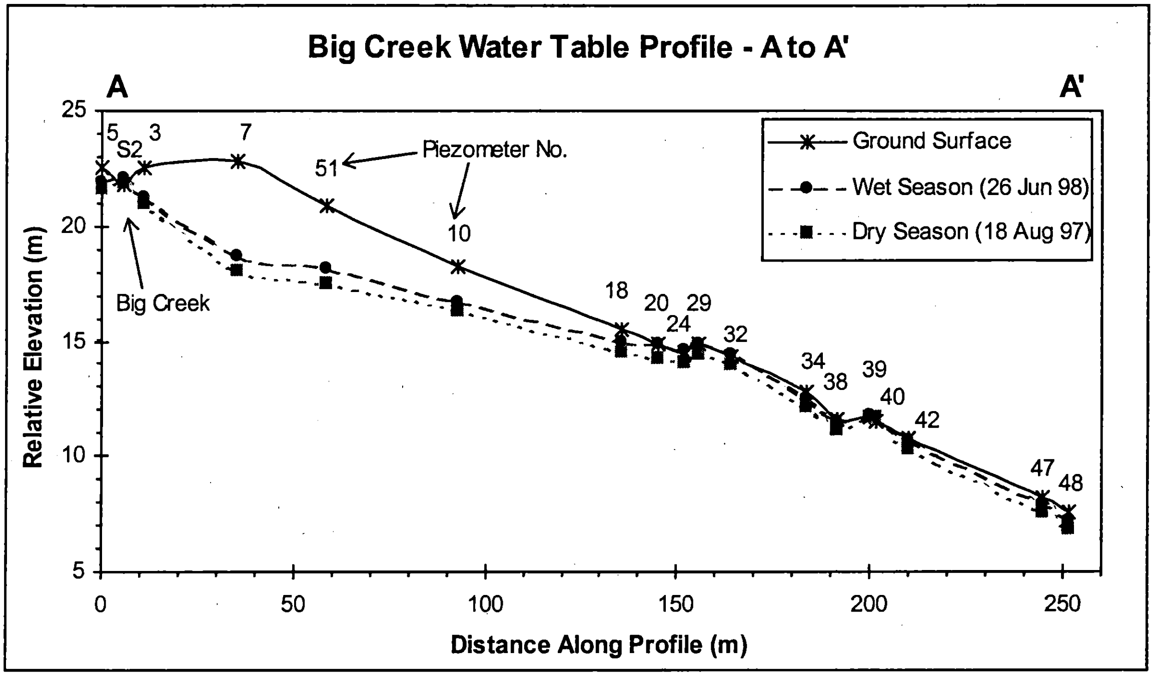


Figure 19. Location of Big Creek water table profiles presented in Figure 20A-D.

A



B

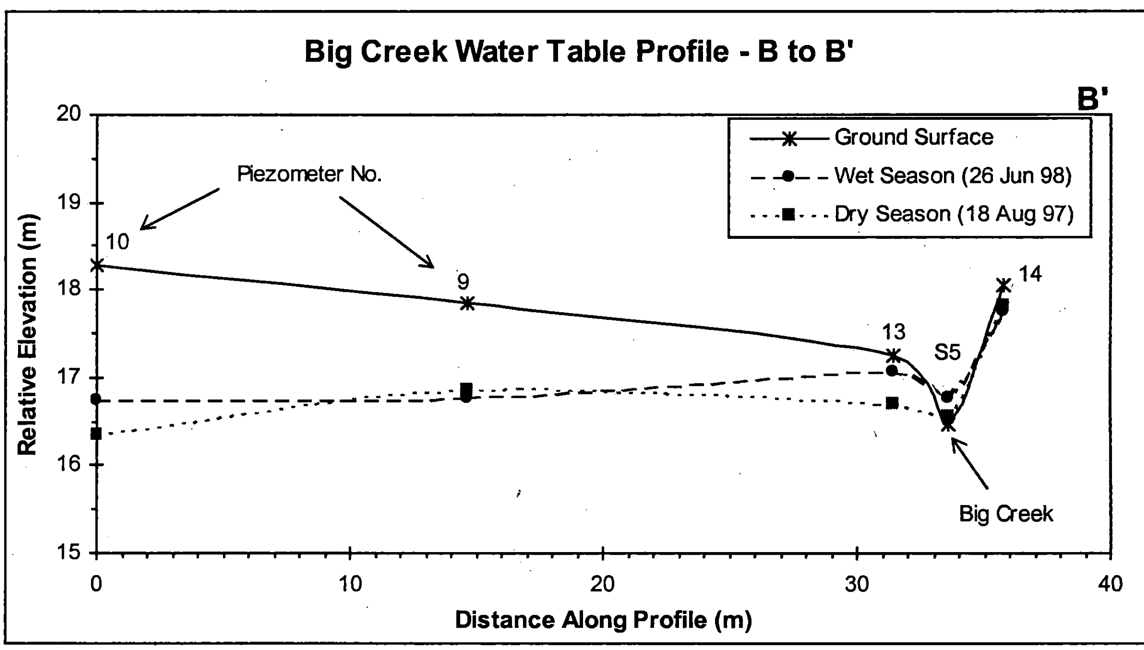
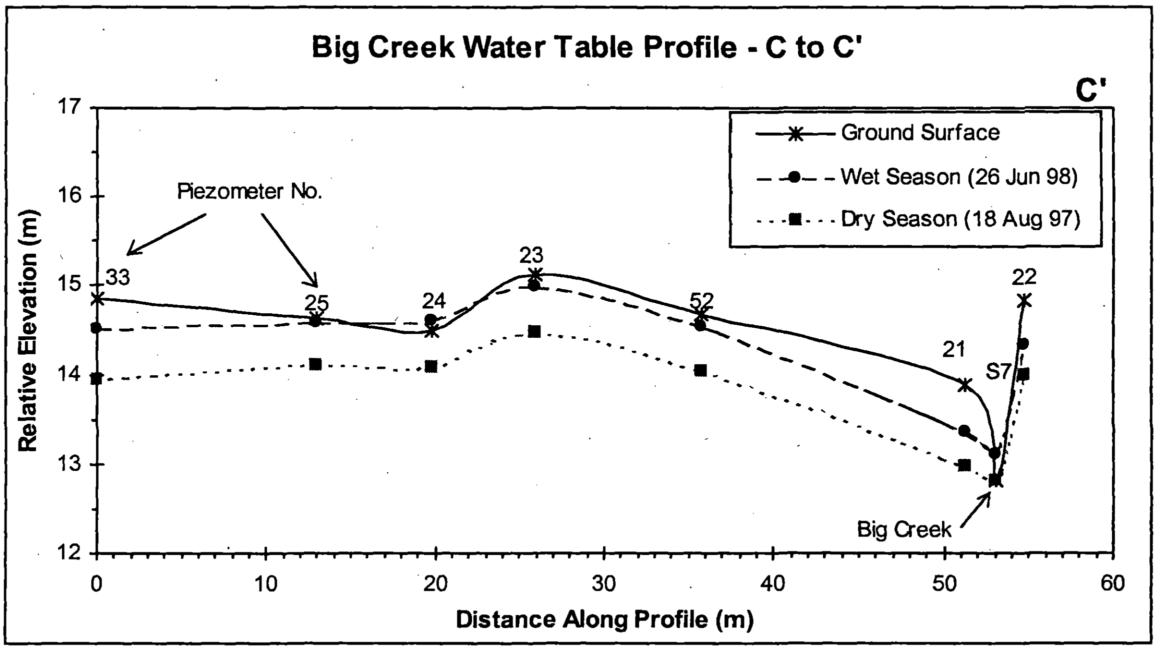


Figure 20. (A) Longitudinal water table profile (A'-A) of Big Creek site for wet and dry Season monitoring events; (B) water table profile along cross section B-B' in upper region of Big Creek site for wet and dry season monitoring events. See Figure 19 for profile locations.

C



D

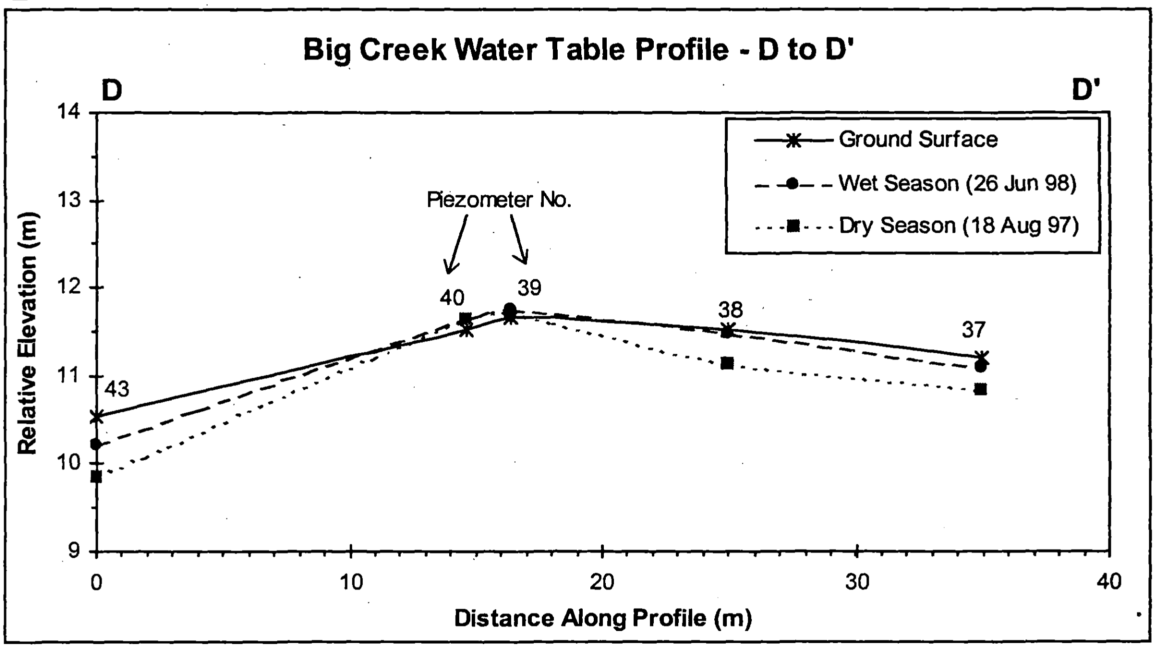


Figure 20. (C) Water table profile along cross section C-C' in mid region of Big Creek site for wet and dry season monitoring events; (D) water table profile along cross section D-D' in lower region of Big Creek site for wet and dry season monitoring events. See Figure 19 for profile locations.

Big Creek has declined from the spring 1998 high flow events, bank storage in the vicinity of the stream remains high. With time, the water table elevation in the vicinity of Big Creek declines, approaching equilibrium with the water level in the creek. During the dry season, the water table flattens out along this profile indicating that lateral flow from the stream is minimal and the majority of groundwater flow is in a downvalley direction (Figure 20A).

Profile C-C' (Figure 20C) is a west to east profile through the midsection of the site. During the wet season, the water table intersects the ground surface in the vicinity of piezometer no. 24, producing a seasonal discharge of groundwater. During the dry season, groundwater discharge is absent and the water table resides 30-40 cm below the ground surface at this location. Big Creek is a gaining stream, receiving subsurface flow from the groundwater system, during both the wet and dry seasons, with a slightly greater hydraulic gradient during the wet season. Profile D-D' (Figure 20D) trends southeast to northwest across the lower region of the site. This profile indicates that groundwater discharges to the surface in the center of the lower region (in and around piezometer nos. 39 and 40) during both the wet and dry seasons. This observation is corroborated by the presence of active seeps in this area of the site. Groundwater flow from this area of discharge is towards Big Creek to the east and to the north (Figure 19 and 20D), with the downvalley hydraulic gradient greater than the lateral gradient towards the stream.

The occurrence of groundwater recharge in the upper region and groundwater discharge in the lower region of the Big Creek site also is observed in time series plots of water table elevation in nested piezometers located in the upper, mid, and lower regions (Figure 21). Nested piezometers are closely spaced piezometers open at different depths in the subsurface that provide data on the vertical hydraulic gradients in the vicinity of the nests (Fetter, 1994). Piezometers 10s and 10d, 26s and 26d, and 43s and 43d (s=shallow; d=deep) are nested piezometers located in the upper, mid and lower regions of the site, respectively. In the upper region, the hydraulic head (that is, the water level elevation) in the shallow piezometer (10s) is greater than the head in the deeper piezometer (10d) and groundwater flow is therefore downward (Figure 21). Groundwater recharge is occurring in the upper region of the site throughout the year (or at least during the field season when measurements were collected). On the contrary, the hydraulic head in the deeper piezometer in the lower region of the site (43d) is greater than the head in the shallower piezometer and groundwater flow is in an upward direction. While this vertical hydraulic gradient occasionally reverses (downward flow), data indicate (Figure 21) that the gradient is predominantly upward. The midsection of the site is a transition zone with downward hydraulic gradients during some years and upward gradients during other years. During the 1997 and 1999 field seasons, water level measurements at piezometers 26s and 26d indicate that a slight downward gradient was present. However, during the 1998 field season, the hydraulic gradient at piezometers 26s and 26d was upward. This upward gradient is associated with the above normal precipitation (Figure 21) received in the area and corresponding higher water table elevations (Figure 17).

In summary, physical hydrologic data indicate that the upper (southern) region of the Big Creek site is a groundwater recharge zone. Sources of water for this recharge zone include subsurface inputs from upgradient valley fill sediments and side valley alluvial fan deposits, as well as flow from Big Creek which is a losing stream along its upper reaches at the site. In

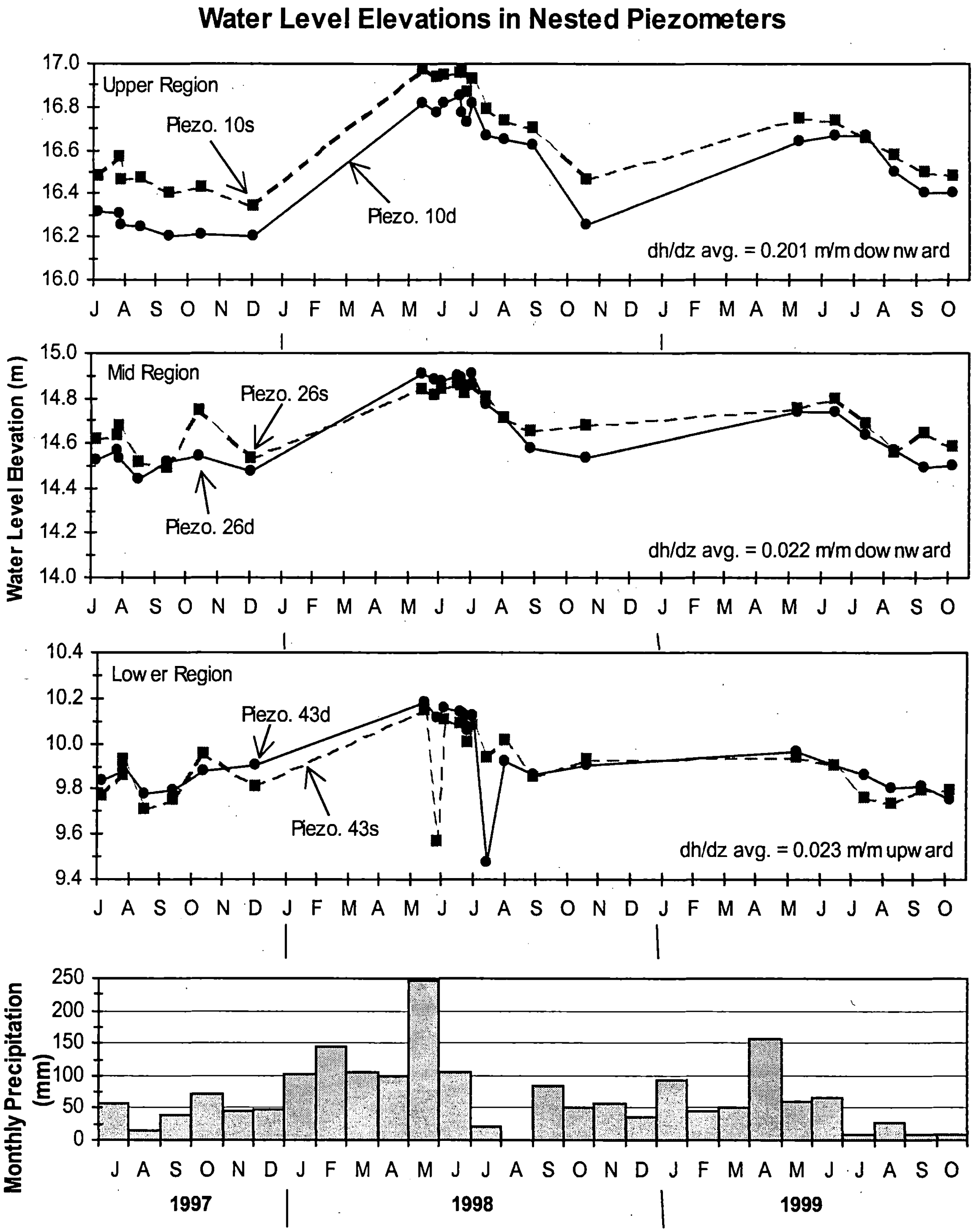


Figure 21. Water level elevations in nested piezometers from upper (piezometers 10s and 10d), mid (piezometer 26s and 26d), and lower regions (piezometers 43s and 43d) of site and monthly precipitation data (USDA/NRCS Big Creek summit weather station) for 1997-1999.

general, groundwater flow is downgradient, parallel to the trend of the axial valley, through the midsection of the site. The lower region of the site, the wet meadow area, is a groundwater discharge zone. A portion of the groundwater discharges in seeps and flows along the ground surface to Big Creek while some groundwater discharges directly into the stream as baseflow. Some groundwater likely continues moving downgradient in the valley fill sediments. The reason for groundwater discharge in this region is likely due to constrictions in the width and thickness of the conductive valley fill sediments. A decrease in the cross sectional area available for subsurface flow, due to a constriction in the width or thickness of the valley fill sediments, can cause groundwater to discharge at the surface in order to maintain continuity within the hydrologic system. Preliminary results from geophysical studies conducted during the 1999 field season suggest that a subsurface bedrock high is present in the vicinity of the wet meadow (Larry Malinconico, Lafayette College, personal communication). A bedrock high in the subsurface would constrict the thickness of the valley fill sediments, which could lead to groundwater discharge and wet meadow formation. Water chemistry data (refer to the next section) support this conclusion as the chemical data are inconsistent with that expected from waters derived from the upwelling of deep groundwater or an interbasin groundwater transfer mechanism (for example, groundwater originating outside of the Big Creek watershed discharging along a deep fault zone).

The Corral Canyon Site

Even though the Big Creek and the Corral Canyon sites were selected because they are thought to be representative of riparian/wet meadow ecosystems in upland watersheds of central Nevada, hydrologically, the two sites are very different. The Big Creek site has a perennial stream associated with it while the Corral Canyon site lacks a perennial channel connecting upstream and downstream reaches. The groundwater flow system at the Corral Canyon site also is more complex than the subsurface system at the Big Creek site. The Corral Canyon site was instrumented with 70 piezometers during the 1997 field season. However, when monitoring commenced the following spring, several of the piezometers located in the midsection of the site were observed to be artesian (that is, the water level in the piezometer was above the ground surface). Artesian conditions are due to the presence of a confining unit in the subsurface with water at pressure beneath the confining layer (Fetter, 1994). An additional 11 piezometers were installed at shallow depths in the area where artesian conditions were present during the summer of 1998. These additional piezometers were installed to better characterize groundwater flow patterns in this area. The distribution of piezometers at the Corral Canyon site is given in Figure 22. A stilling well was not installed at this site because of the absence of a perennial stream system.

Figure 23 provides a summary of the depth to the water (average depth $\pm$ 1 standard deviation) during the 1997-1999 field seasons for piezometers located in the upper (western), mid, and lower (eastern) regions of the site. Water level data for the midsection of the site have been subdivided into two groups: data from piezometers open in the confined unit (Figure 23, Mid Region-Deep) and data from piezometers open in the unconfined unit (Figure 23, Mid Region-Shallow). Because the unconfined piezometers were not installed until mid-summer 1998, data before this time were unavailable for this time series plot. The greatest depths to water in the groundwater system at the Corral Canyon site are located at the upper (western) region of the site. The greatest variation in depth to water also is exhibited in data from

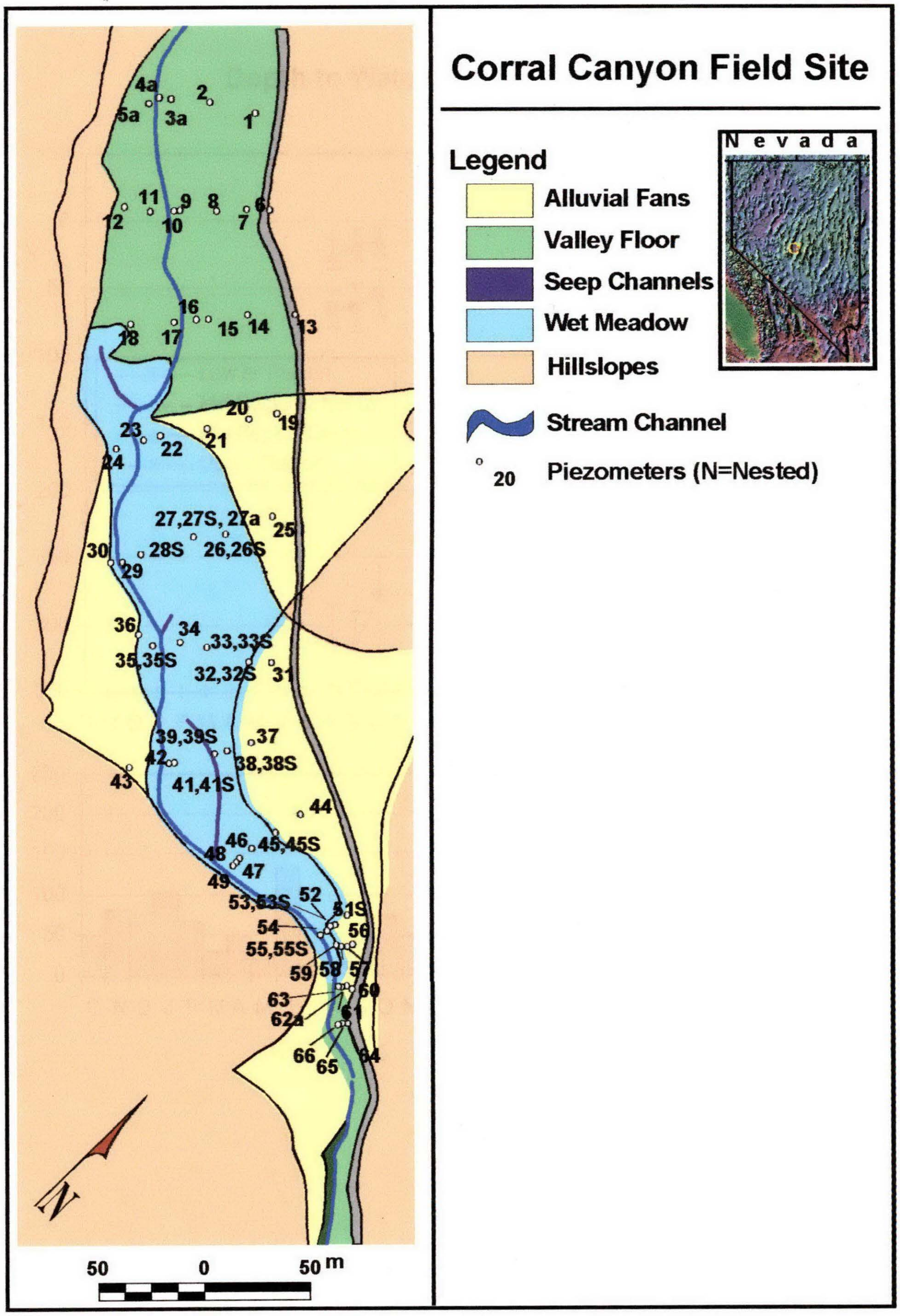


Figure 22. Piezometer and monitoring well locations at Corral Canyon site.

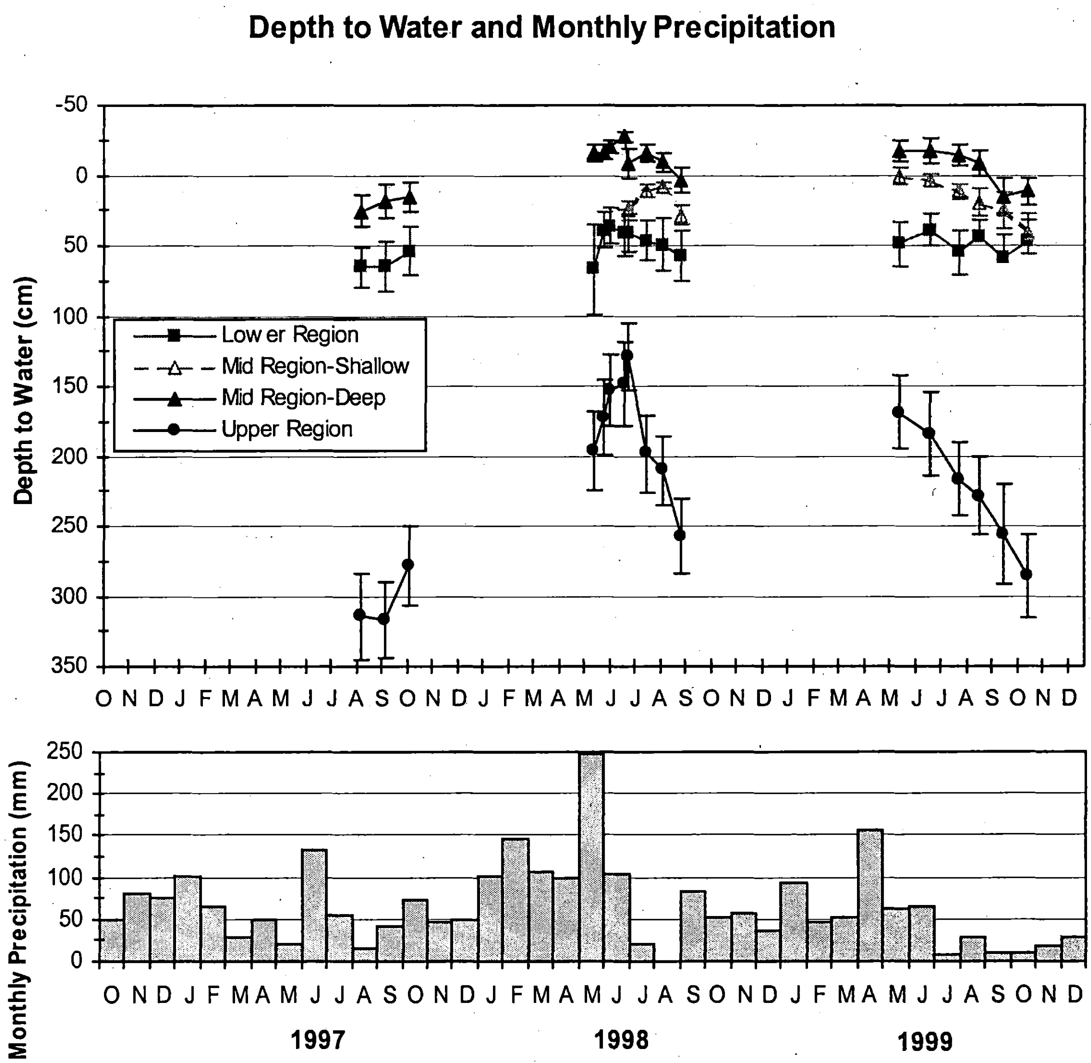


Figure 23. Average depth to water (± 1 standard deviation) in upper, mid, and lower regions of the Corral Canyon site and monthly precipitation data collected at USDA/NRCS Big Creek summit weather station for 1997-1999.

piezometers in the upper region. The shallowest depths to water occur in piezometers in the mid region of the site. Note that the average depth to water in the deep piezometers is greater than the depth to water in the shallow piezometers (Figure 23), indicating that an upward gradient exists in this region of the site. The data also indicate that a confining or semi-confining unit (depending on the thickness and lateral continuity of the unit) is present between the deep and shallow piezometers because the average hydraulic head in the deeper piezometers rises above the ground surface (artesian conditions) for the majority of the 1998 and 1999 field seasons. Observations recorded during field reconnaissance using a tile probe to qualitatively ascertain shallow stratigraphy suggest that a denser, clay rich unit is indeed present in the subsurface of the middle region of the site (Bob Barr, IUPUI, personal communication). This conclusion is supported by the sediment core data obtained for the site which demonstrate that several peat and fine-grained (silty loam) mineral layers exist (at least locally) within 1 m of the ground surface (see, for example, Figure 13). This confining or semi-confining unit appears to be absent in both the upper and lower regions of the site. The depth to water in the lower region is slightly greater than the depths recorded in the midsection (Figure 23).

The direction of groundwater flow in the unconfined system generally is parallel to the trend of the axial valley, flowing northwest to southeast through the site, during both periods of higher (Figure 24, data collected 22 July 1998) and lower water levels (Figure 25, data collected 01 September 1998). During the wet season monitoring event (Figure 24), a divergent groundwater flow pattern (flow is perpendicular to equipotentials) is present in the upper region. This may be due to an apparent increase in the width of the valley fill sediments. The equipotentials also deflect somewhat to the south in the vicinity of the upstream-most alluvial fan, likely due to subsurface groundwater input from the fan deposits (see Figure 8 for distribution of landforms at the site). Groundwater flow exhibits a convergent pattern in the lowermost portion of the site due to a constriction in the width of the valley fill sediments and likely cause groundwater to discharge to the stream system. Similar groundwater flow patterns exist as the system dries out and water levels decrease (Figure 25). However, groundwater flow patterns in the unconfined system are more complex in the middle region. This is likely due to interactions between the unconfined unit and underlying confined unit.

Maps of the potentiometric surface (the surface representative of the level to which water rises in wells open to the confined unit; Fetter, 1994) for the midsection of the site have been generated for both wet season (Figure 26) and dry season (Figure 27) monitoring events. The potentiometric surface for the wet season (Figure 26) indicates that while groundwater flow generally is from west to east (in a downvalley direction), there is a component of flow from the alluvial fans along the northern edge of the site towards the stream channel. This suggests that subsurface water from the fan deposits has more of an impact during the wet season. Groundwater flow in the confined/semi-confined unit follows the trend of the axial valley during the dry period (Figure 27).

Water level profiles have been produced for several cross sections through the Corral Canyon site (Figures 28 and 29A-E) to illustrate groundwater gradients and the differences in groundwater levels between wet and dry seasons. Figure 28 is a key to the location of the water level profiles illustrated in Figures 29A-E. The data used to create these profiles are the same data used to generate Figures 24-27. Figure 29A (Profile A-A') is a longitudinal profile along

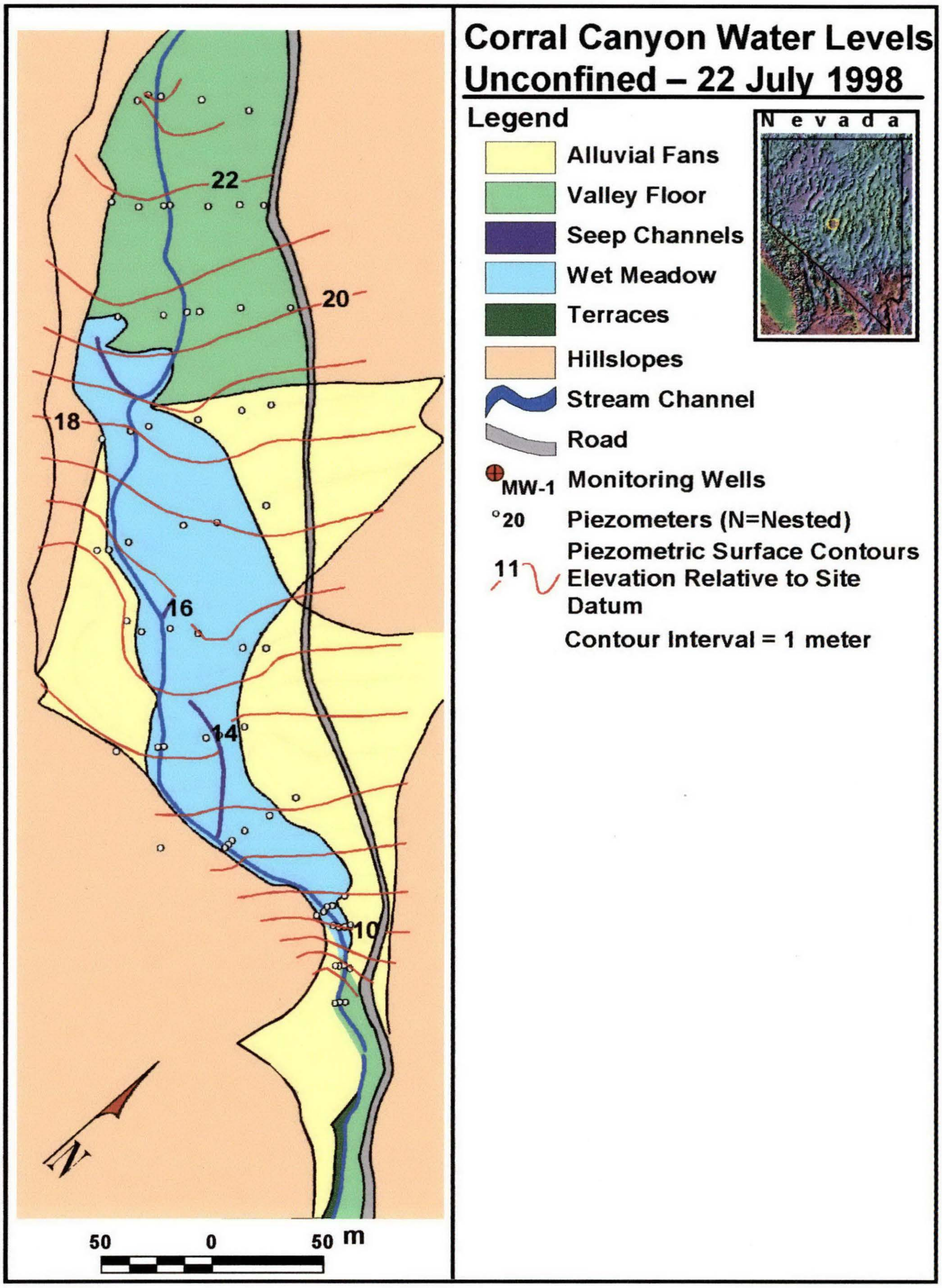


Figure 24. Corral Canyon water table surface for wet season monitoring event (22 July 1998).

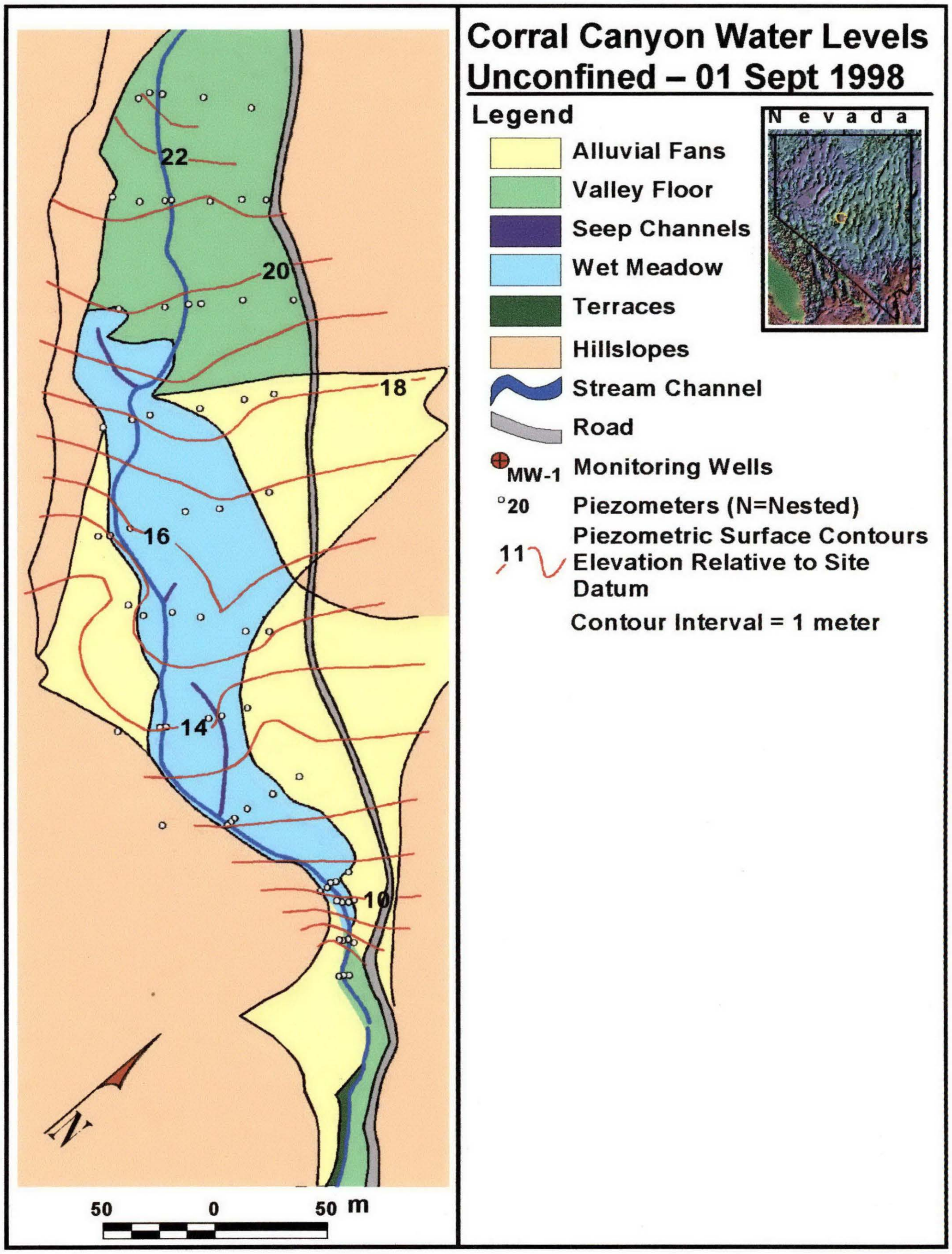


Figure 25. Corral Canyon water table surface for dry season monitoring event (01 September, 1998).

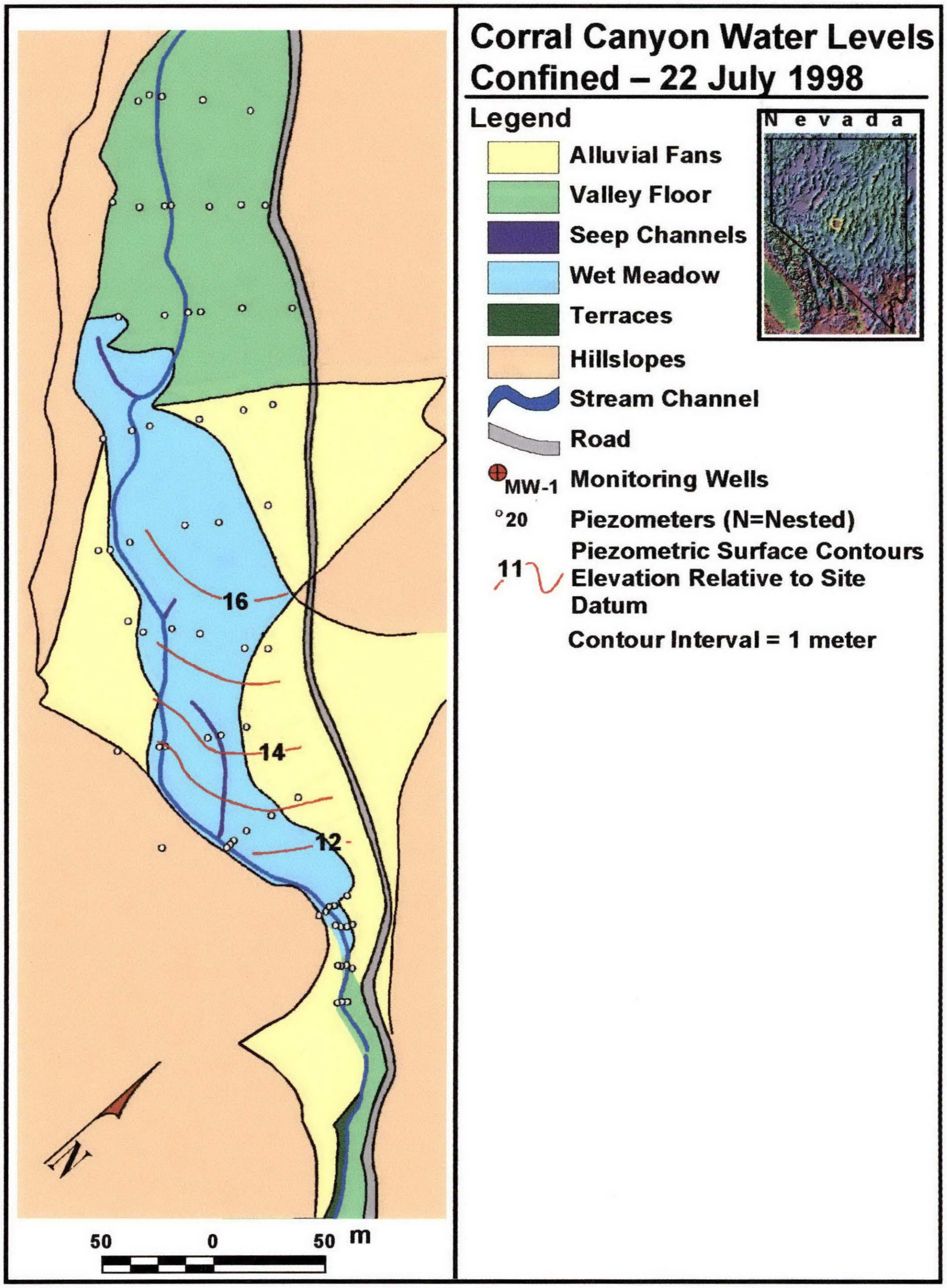


Figure 26. Corral Canyon potentiometric surface for wet season monitoring event (22 July, 1998).

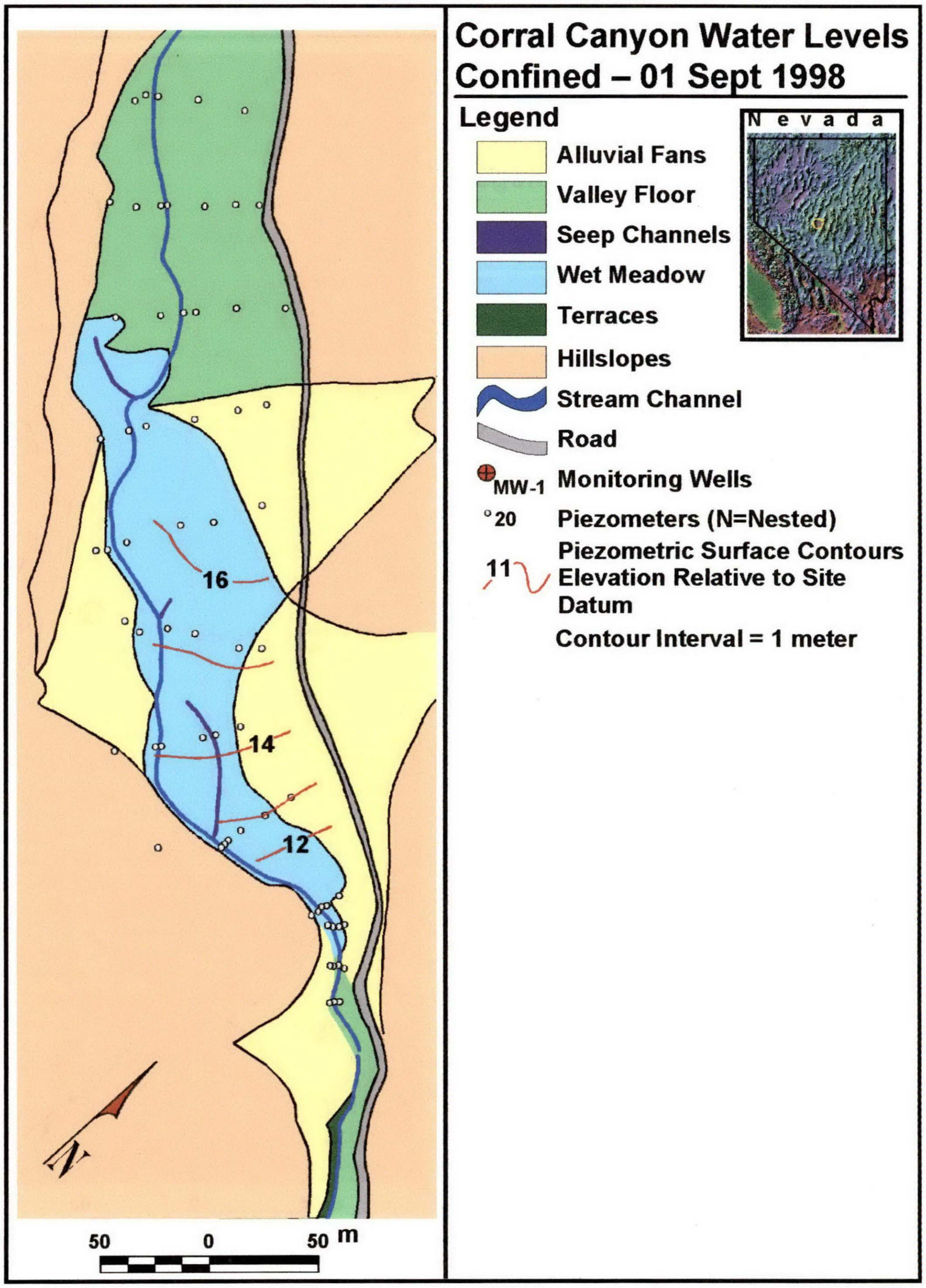


Figure 27. Corral Canyon potentiometric surface for dry season monitoring event (01 September, 1998).

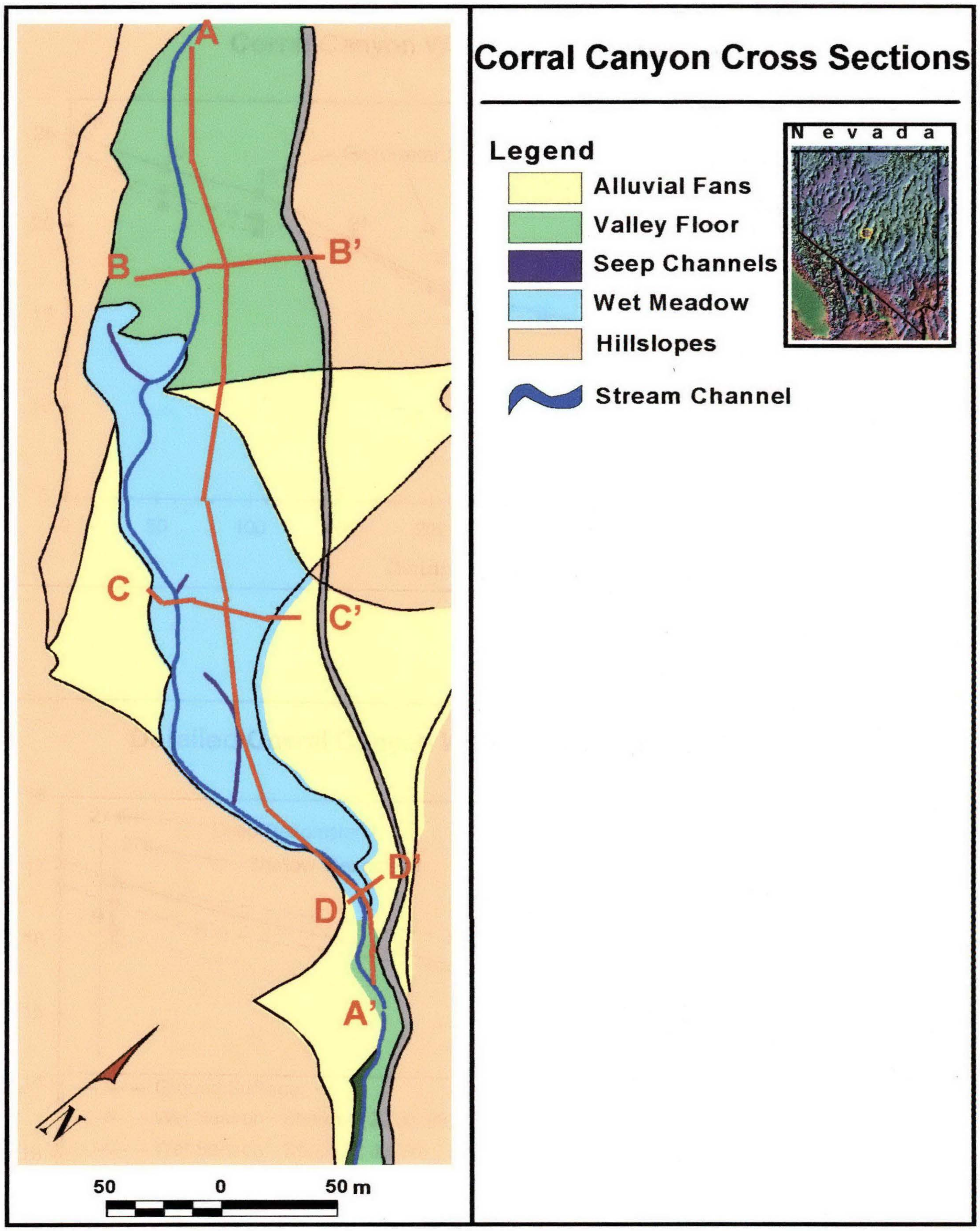
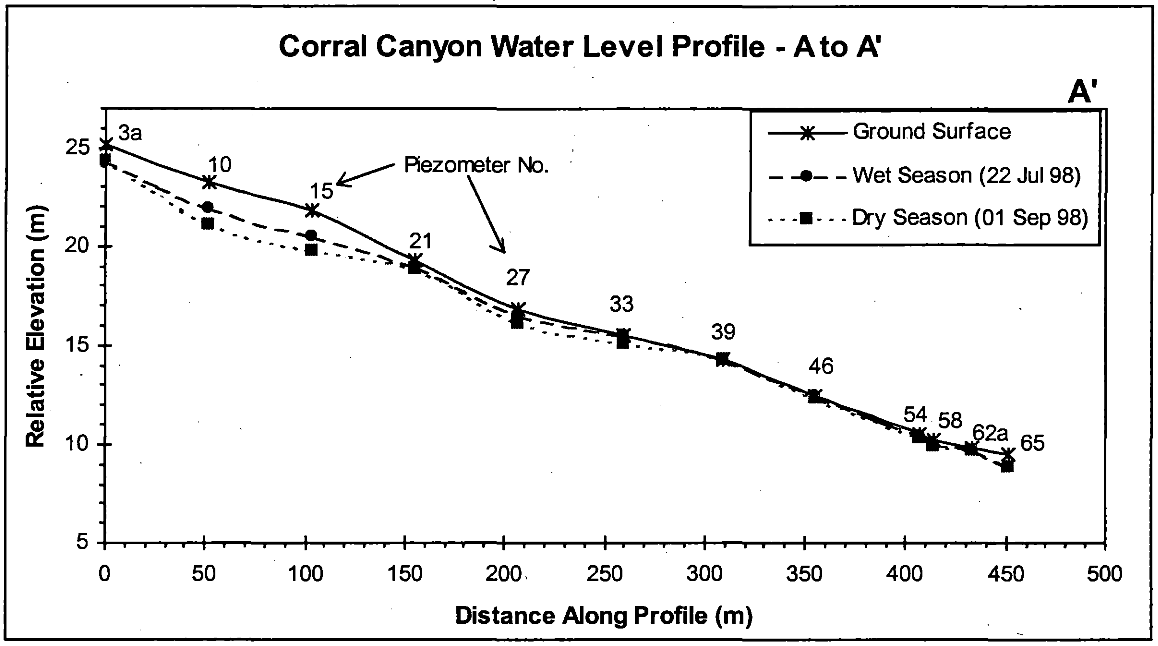


Figure 28. Location of Corral Canyon water level profiles presented in Figures 29A-E).

A



B

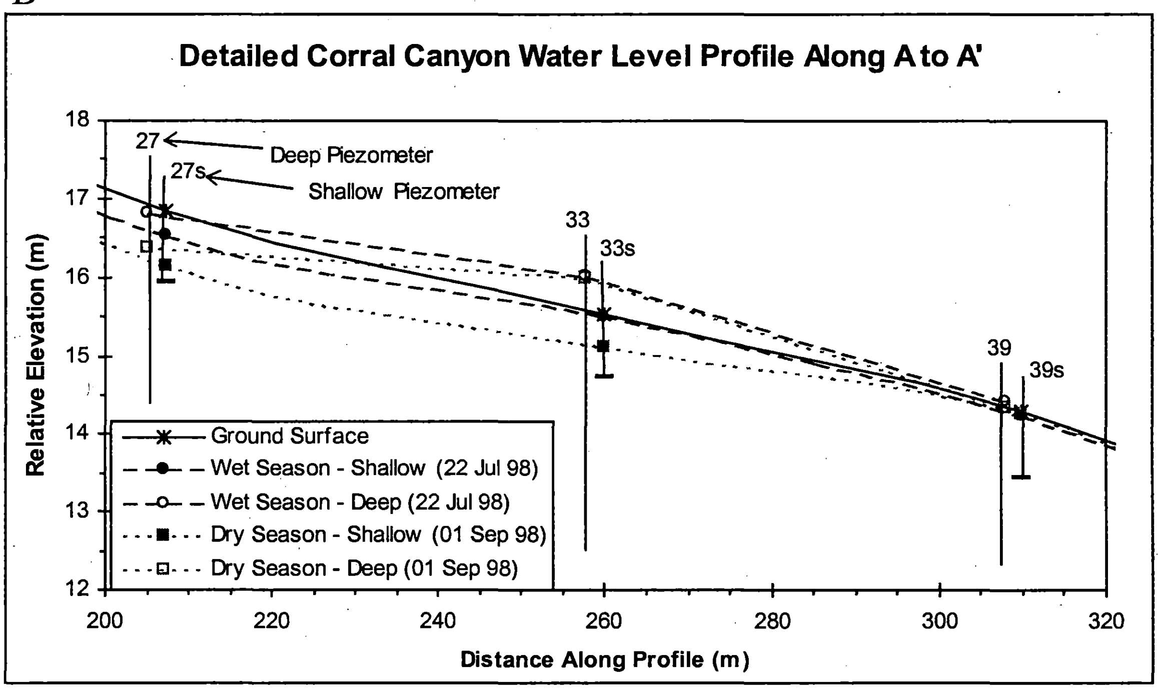
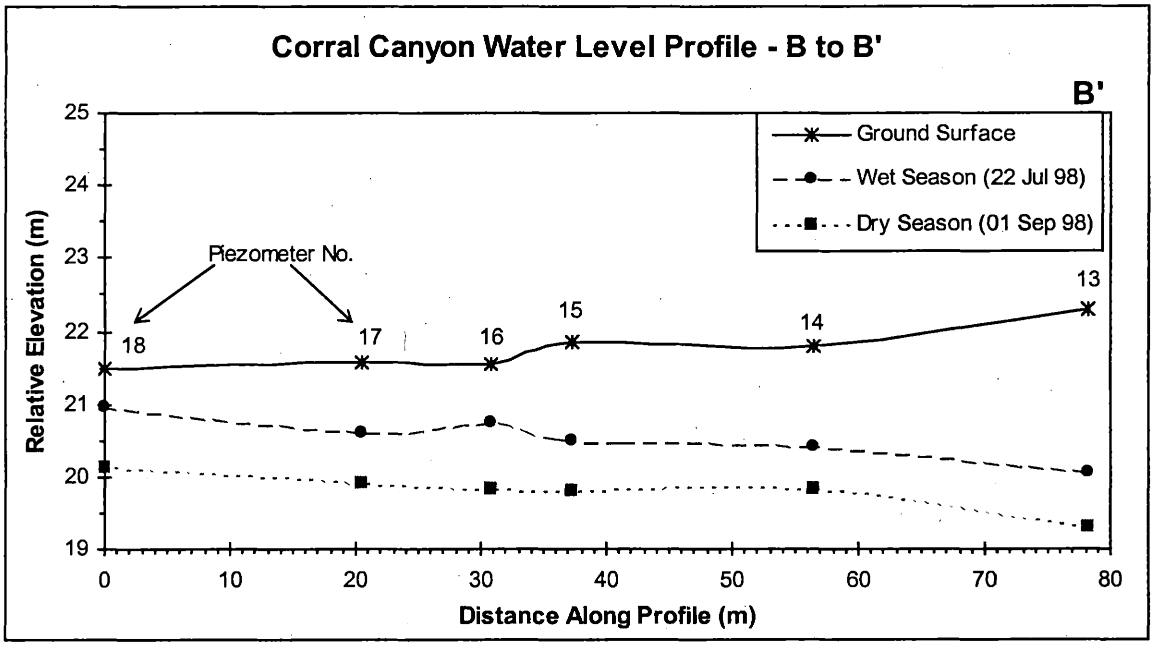


Figure 29. (A) Longitudinal water table profiles (A-A') of Corral Canyon site for wet and dry season examples; (B) Longitudinal profiles (cross-section (A-A'), piezometers 27s/d, 33s/d, and 39s/d) of water table and potentiometric surfaces in area where artesian conditions have been observed for wet and dry season examples. See Figure 28 for profile locations.

C



D

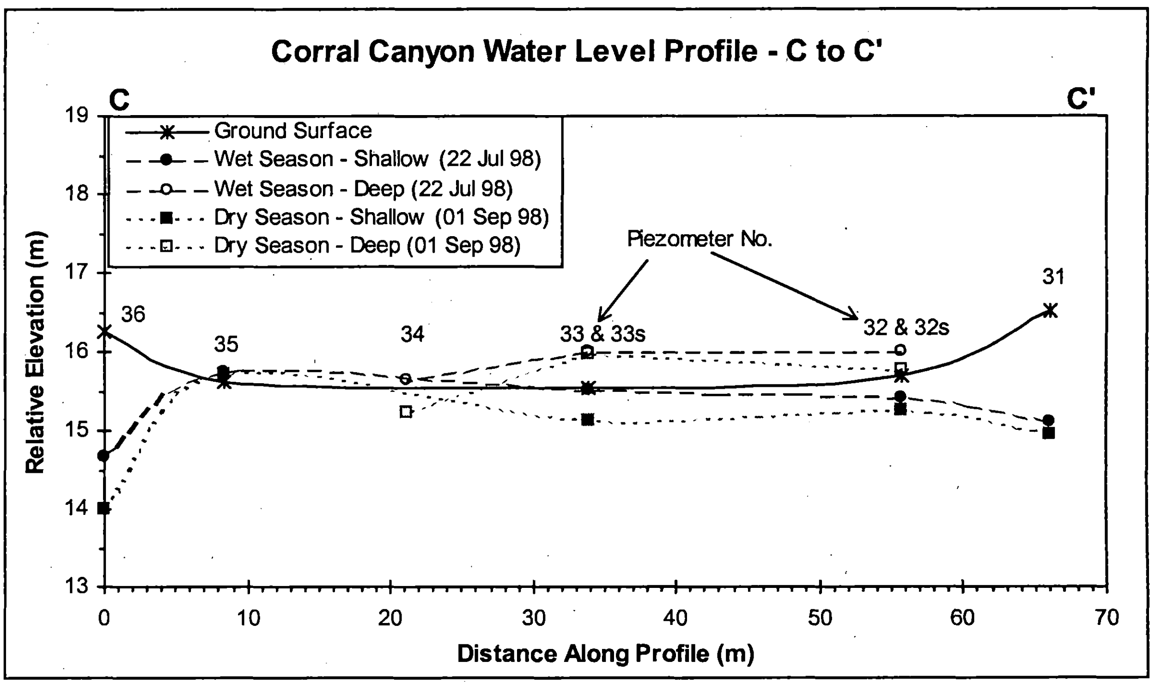


Figure 29. (C) Water level profiles along cross section B-B' in upper region of Corral Canyon site for wet and dry seasons; (D) Water table and potentiometric surface profiles along cross section C-C' in mid region of Corral Canyon site for wet and dry season examples. See Figure 28 for profile locations.

E

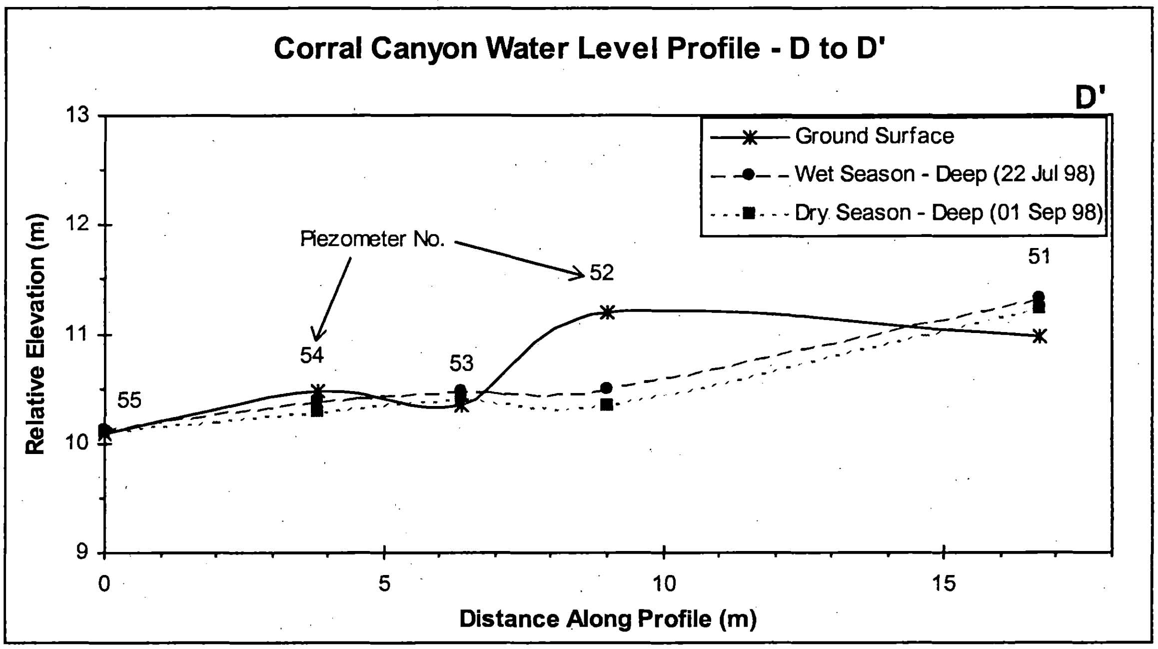


Figure 29. (E) Water level profiles along cross section D-D' in lower region of Corral Canyon site for wet and dry season examples.

the length of the axial valley. This water table profile indicates that during both the wet and dry seasons, water levels in the upper region of the site are 1 to 3 m below the ground surface. The water levels approach the ground surface near the upper end of the upstream-most alluvial fan (Figure 22, piezometer no. 21). Groundwater levels remain at or near the ground surface throughout the rest of the site along the centerline of the axial valley. Figure 29B is an enlargement of Profile A-A' along the profile where artesian conditions exist and this figure demonstrates the complexity of groundwater movement in Corral Canyon. Included in this profile are the water table and potentiometric surfaces for the wet and dry season examples based on shallow and deep piezometer data. During the wet season monitoring event, the water table (corresponding to the unconfined groundwater system) is at or near the ground surface. The potentiometric surface (corresponding to the confined/semi-confined groundwater system) is at or above the ground surface at the three piezometers included in the enlarged profile. An upward vertical gradient is evident along most of this profile. The upward gradient is greatest near piezometer nos. 33s/33d and least near piezometer nos. 39s/39d. The water table is at a slightly greater depth in the dry season example. Data indicate that the potentiometric surface is at or near the ground surface at piezometer nos. 27d and 39d. However, the hydraulic head in piezometer no. 33d during the dry season example is similar to the head for the wet season example. This indicates that the upward vertical gradient at this location is greater during this particular dry season monitoring event than during the wet season example. This observation may be due to temporal influences of evapotranspiration on water table levels in the wet meadow area.

Profile B-B' (Figure 29C) is a transect perpendicular to the trend of the axial valley in the upper region of the site. The water table along this profile is relatively flat. While there is a slight hydraulic gradient to the north, profile A-A' indicates that the major component of groundwater flow is downvalley. This downvalley gradient in the valley fill sediments also exists at profiles C-C' and D-D', but the orientation of these profiles conceals this component of groundwater flow. Profile C-C' (Figure 29D) also is perpendicular to the trend of the axial valley, located in between the two side valley alluvial fans entering the axial valley from the north (Figure 8). Groundwater flow along this transect is difficult to interpret. It is unclear whether piezometer no. 34 is in the unconfined or confined system. Also, water levels in piezometer nos. 35s and 35d tend to be very close to one another. Groundwater appears to move away from the center of the discharge area. Numerous seeps and springs are present in the midsection of the site, highlighting the complexity of groundwater flow in this area. More information is necessary to better characterize groundwater flow at this location. Profile D-D' (Figure 29E) is another cross valley transect located in the lower region of the site. A component of groundwater flow in this region is towards the south where groundwater likely discharges to the stream channel.

In summary, the hydrologic system at the Corral Canyon site is more complex than the system at the Big Creek site. A perennial stream does not flow the length of the Corral Canyon site. Groundwater is the major source of water entering the site, moving downvalley through the valley fill sediments. A limited amount of surface water also may enter the site from an upstream direction during high rainfall events, but this has not been documented during site visits. Groundwater moves in a west to east direction through the site. The groundwater system also receives subsurface input of water from side valley alluvial fan deposits. Water level data

indicate that groundwater at depth is confined or semi-confined in the midsection of the site. Deep piezometers exhibited artesian conditions during most of 1998 and 1999. Field observations suggest that the confining/semi-confining unit is a dense, clay-rich layer and groundwater in the valley fill sediments and the alluvial fan deposits influences heads in the confined/semi-confined flow system. Groundwater seeps and springs are present throughout the midsection of the site, discharging to narrow channels and moving downstream as surface flow. Stream flow may be perennial at the lower end of the site based on observations made during monitoring events during the field season.

The reason for groundwater discharge in the midsection of the site is still under investigation. Oxygen isotope data (refer to geochemistry results in the next section) suggest that the water is not derived from the upwelling of deep groundwater or an interbasin groundwater transfer mechanism (e.g., the movement of groundwater along faults or fractures). Preliminary geophysical results suggest that valley fill sediments thin over a bedrock high in this area (Larry Malinconico, Lafayette College, personal communication). A decrease in the cross sectional area available for subsurface flow could produce the groundwater discharge zone observed at the Corral Canyon site.

Implications of Geochemical Data to Source of Water in the Wet Meadows

(Contributed by Eliot Atekwana, IUPUI)

To better understand the sources of water to the wet meadow systems at the two field sites, major ion chemistry and stable isotopes analyses were conducted on stream waters, shallow groundwater, surface runoff from the wet meadows, and groundwater seeps/springs in and near the wet meadow complexes. The results of the summer and fall 1998 and summer 1999 analyses are presented in Table 2. The major ions analyzed included the metals Ca, Mg, Na, K, Fe, and the non metals NO_3^-, SO_4^{2-}, Cl^-, HCO_3^-. In addition, electrical conductivity, pH, temperature and dissolved oxygen measured for some samples are also shown in Table 2. Stable isotopes analyses consisted of dissolved inorganic carbon (DIC) and oxygen isotopes.

Determining the source of water in the wet meadow complex using major ion chemistry is based on the difference in chemical evolution in stream and groundwater systems. For groundwater, weathering reactions in the aquifer control the major ion chemistry (e.g. Freeze and Cherry, 1979, Domenico and Swartz, 1990, Wassenar et al., 1991). Stream water chemistry is primarily controlled by the ratio of direct runoff relative to baseflow. Direct runoff in headwater catchments such as Big Creek and Corral Canyon consist primarily of snowmelt with minimal contribution to the major ion chemistry. Streamflow generally increases downstream, augmented by groundwater contribution (baseflow) and stream chemistry should change but will be distinct from that of groundwater. Groundwater is generally characterized by higher concentrations of cations and anions than stream water. Thus if the source of water for the wet meadow complexes is stream water, the major ion chemistry should be similar to that of stream water except where it can be demonstrated that physical aspects of groundwater hydrology excludes this possibility. On the other hand, if the source of water in the wet meadow complex is groundwater, the geochemistry of the shallow groundwater and wet meadow runoff should be

Table 2: Summary of Geochemical Data

		Remarks	Temp °C	pH SU	DO % sat	Cond υS	Alk mg/L	Cl mg/L	NO_3^- mg/L	SO_4^{2-} mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Fe mg/L	DIC mgC/l	$\delta^{13}C$ ‰	$\delta^{13}O$ ‰
BIG CREEK																		
Summer/Fall 1998	runoff -1	Birch Seep at stream	6.49	7.38	17.5	414	NA	NA	NA	NA	NA	NA	NA	NA	NA	71.6	-10.3	-16.2
	seep-1	Birch Seep at source	6.97	7.35	16.6	414	NA	NA	NA	NA	NA	NA	NA	NA	NA	62.8	-10.7	-16.2
	seep-2	adit seep	7.07	7.40	17.5	502	NA	NA	NA	125	7.4	NA	89.5	45.7	0.014	82.7	-10.7	-16.0
	stream-1	upstream - stream section 0	5.23	8.00	15.3	341	NA	NA	NA	57.8	5.8	NA	56	22.6	0.135	51.4	-9.5	-16.1
	stream-2	mid-site stream x-section 1	5.47	7.97	14.8	342	NA	NA	NA	46.9	6	NA	36.1	15.6	0.135	53.4	-9.6	-15.8
	stream-3	mid-site stream x-section 2	5.14	8.09	17.3	363	NA	NA	NA	45.3	5.7	NA	65.6	25.3	0.135	52.4	-9.5	-16.3
	stream-4	mid-site stream x-section 3	4.74	7.95	19.7	381	NA	NA	NA	50	5.7	NA	59.3	23.7	0.135	50.5	-9.5	-16.1
	stream-5	downstream stream x-section 4	4.53	7.07	15.0	383	NA	NA	NA	31.3	5.8	NA	69.8	26.4	0.135	51.0	-9.5	-16.3
	Groundwater-1	MW-24	4.00	7.06	16.0	657	NA	NA	NA	23.8	13.9	NA	164	74.9	5.59	114.6	-14.6	-16.1
	Groundwater-2	MW-3	1.49	7.17	17.1	496	NA	NA	NA	50	10.2	NA	144	64.3	1.75	86.5	-11.9	-16.3
	Groundwater-3	MW-32	1.88	7.36	16.0	574	NA	NA	NA	59.4	9.1	NA	151	60.3	2.47	132.1	-15	-15.7
	Groundwater-4	MW-4	4.53	7.31	14.5	623	NA	NA	NA	183	10.5	NA	60.5	66.1	1.7	89.5	-9.9	-16.0
	Groundwater-5	pz-51	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	35.4	-15	-16.3
Summer 1999	runoff-1	Runoff from wet meadow into stream	16.8	8.69	NA	600	205	3.2	<0.2	62.6	23.6	1.6	29.9	35.2	5.2	63.8	-10.6	-16.7
	runoff-2	Surface outflow at base of site	11.4	8.74	NA	630	329	3.5	0.2	62.6	1.0	0.2	34.0	48.4	34.8	72.1	-10.2	NA
	seep-1	Birch Seep	10.5	8.17	NA	460	290	3.4	0.4	66.0	8.6	0.7	28.8	35.3	4.2	66.4	-10.9	NA
	seep-2	Adit Seep	10.2	7.36	NA	590	317	3.5	<0.2	85.5	0.2	0.9	30.1	40.8	6.6	72.2	-10.9	NA
	stream-1	Upstream of study site	9.4	9.42	NA	380	180	1.8	0.4	29.1	36.6	2.3	22.9	20.9	3.6	43.1	-9.3	-16.8
	stream-2	Stream at middle of site	12.2	9.22	NA	390	138	1.9	0.4	34.2	26.6	1.7	21.4	20.2	6.7	44.7	-9.6	-16.8
	stream-3	Stream below site	12.3	9.52	NA	380	137	1.9	0.4	33.5	29.6	1.9	23.0	20.8	3.0	45.3	-9.3	-16.8
	Groundwater-1	MWA5	10.1	7.73	NA	760	496	2.7	<0.2	59.8	24.6	2.8	52.1	48.1	21.8	120.3	-15.6	-16.6
	Groundwater-2	MWA6	9.5	7.84	NA	540	316	2.9	<0.2	63.2	24.2	2.9	33.1	38.6	8.0	76.1	-12.0	-16.7
	Groundwater-3	MWA4	9.9	7.87	NA	540	320	2.5	<0.2	49.6	14.9	1.8	32.6	35.8	5.9	NA	NA	NA
	Groundwater-4	MW3	10.8	7.97	NA	600	386	3.2	<0.2	88.9	8.3	1.2	35.8	39.4	24.0	93.0	-13.4	-16.6
	Groundwater-5	MW4	10	7.94	NA	860	395	3.5	<0.2	133.0	8.0	0.7	33.5	56.7	3.9	86.5	-9.8	NA
	Groundwater-6	MWA1	10.5	7.52	NA	1100	583	4.7	5.5	175.0	7.4	1.1	72.6	72.7	16.4	164.2	-13.9	NA
	Groundwater-7	MW32	10.3	7.94	NA	750	497	3.4	0.5	95.0	1.1	0.3	55.3	52.6	26.3	125.1	-14.4	NA
CORRAL CANYON																		
Summer/Fall 1998	seep-1	seep hole	8.4	5.99	13.1	231	NA	NA	NA	NA	NA	NA	NA	NA	NA	31.5	-16.3	-16.6
	seep-2	upper seep confl.	2.6	6.97	16.0	75	NA	NA	NA	NA	NA	NA	NA	NA	NA	18.2	-9.9	-16.7
	seep-3	left seep head	8.7	7.00	12.6	191	NA	NA	NA	NA	NA	NA	NA	NA	NA	25.9	-15.6	-16.8
	stream-1	below knickpoint	4.7	6.45	13.0	389	NA	NA	NA	NA	NA	NA	NA	NA	NA	18.7	-11.2	-16.2
	stream-2	above knickpoint	4.3	6.75	16.7	168	NA	NA	NA	NA	NA	NA	NA	NA	NA	18.1	-10.8	-16.7
	Groundwater-1	pz-37	7.6	6.81	12.4	168	NA	NA	NA	NA	NA	NA	NA	NA	NA	47.1	-15.5	-16.7
	Groundwater-2	pz-43	5.3	9.19	14.0	6	NA	NA	NA	NA	NA	NA	NA	NA	NA	32.1	-19.5	-16.4
Summer 1999	runoff-1	Wet meadow out flow to stream	24.0	8.35	NA	290	144	12.7	<0.2	8.6	25.4	8.7	14.2	7.6	73.6	36.7	-15.0	-16.5
	seep-1	seep upgradient of site	10.2	7.46	NA	270	100	12.6	<0.2	18.8	24.4	4.9	10.4	5.7	11.4	31.1	-17.3	-17.6
	seep-2	Seep at center of site	6.3	8.3	NA	270	100	12.2	<0.2	20.5	26.2	4.8	10.5	6.2	15.7	29.4	-13.4	NA
	seep-3	Seep below raised bog	7.9	7.72	NA	240	92	12.2	<0.2	18.8	20.7	4.2	8.2	5.1	4.7	29.2	-16.9	-17.3
	seep-4	Seep at south valley wall	9.3	7.01	NA	410	161	17.9	<0.2	34.2	38.6	6.7	16.1	9.2	11.4	69.5	-17.1	-17.1
	stream-1	Upstream of site (east section)	10.8	8.65	NA	230	108	11.3	<0.2	16.8	17.0	5.6	9.6	5.8	33.4	23.0	-15.0	-17.6
	stream-2	Upstream of site (west section)	10.7	8.02	NA	220	93	10.8	0.3	16.4	15.9	3.7	7.8	4.4	24.5	26.2	-16.5	-17.9
	stream-3	Stream at middle of site	17.2	8.87	NA	230	98	10.8	<0.2	14.7	22.5	5.6	9.8	5.8	167.0	23.6	-15.0	-17.3
	stream-4	Downstream of site	17.5	8.8	NA	270	129	12.6	<0.2	14.7	19.1	5.9	11.4	6.3	239.0	28.7	-13.0	-17.1
	Groundwater-1	PZ18	9.7	7.67	NA	230	90	11.3	0.2	18.5	21.8	4.4	9.3	5.2	57.5	28.8	-17.1	-17.7
	Groundwater-2	PZ17	10.4	7.83	NA	250	96	12.6	<0.2	18.8	21.3	4.7	9.9	5.8	13.2	30.7	-16.8	-17.3
	Groundwater-3	PZ12	14.7	7.2	NA	280	133	11.7	<0.2	9.57	25.9	7.3	11.5	6.6	123.0	39.1	-17.8	-17.0
	Groundwater-4	MW5	10.9	7.65	NA	240	109	12.2	0.2	18.8	21.4	5.1	10.1	5.7	57.6	33.0	-16.4	-17.0
	Groundwater-5	PZ26	8.3	6.96		250	98	12.0	<0.2	17.1	26.6	6.1	9.8	5.7	156.0	34.7	-19.9	-17.0

similar. It should also be similar with seeps and springs known to be of groundwater origin at these sites.

Stable isotopes can also provide insights into the source of water that sustains riparian wet meadow vegetation. The utility of stable oxygen isotopes for determining water sources is based on the fact that temporal variations in the source of stream and groundwater should occur because the mechanism of flow and the residence of water derived from precipitation and flowing through these systems are different. In addition, stream water is generally of local origin (within the watershed) while contributions to groundwater could come from interbasin flow through fracture or regional type flow with an isotopic signature different from the local precipitation. The utility of carbon isotopes in distinguishing the dominant source of water within wet meadow complexes is based on difference in carbon evolution of surface and groundwater systems. Groundwater dissolved inorganic carbon (DIC) concentration and isotopic composition is controlled by soil carbon dioxide composition, and its partial pressure and water mineral reaction in the aquifer. Because both the DIC concentration and its isotopic value are controlled by the nature of groundwater/mineral interaction, it can be coupled with major cations such as Ca, Mg, Na and K to validate groundwater sources to the wet meadow complexes.

Although more than one sampling event was carried out for geochemical and isotopic analyses, the following interpretation is based on the sampling event of fall 1999 which represent the most complete ion and isotopic analyses. The summer and fall sampling events although not analyzed for similar major ion and isotopic data would lead to similar conclusions.

Big Creek: Major Ion Chemistry

The major ion chemistry of Big Creek water samples are shown in Figure 30. The major ion chemistry is mainly controlled by carbonate mineral dissolution and the waters from this site can be classified as a Ca-Mg-HCO_3^- geochemical type. Although there is scatter in the data on the Piper plot, stream water is geochemically different from groundwater, seeps/springs and runoff from the wet meadow complex (Figure 30). Stream water is lower in Ca and Mg with respect to the other water samples. In addition, seepage/spring waters known to have a groundwater source cluster with shallow groundwater and runoff from the wet meadow complex, indicating a genetic relationship. This genetic relation suggests that the meadow complex is fed primarily by groundwater.

Big Creek: Stable Oxygen Isotopes

Stable oxygen ($\delta^{18}O$) isotopic values for Big Creek range from –17.3 to –16.5 $^0/_{00}$ for summer of 1999 (Table 2). The $\delta^{18}O$ values are similar to values reported for this part of the Great Basin (Davisson et al., 1999). Groundwater, seeps/springs, runoff from the wet meadows and stream water show no significant difference in the measured $\delta^{18}O$. The data suggest that the source of water that supply the stream, seeps/springs, meadow runoff and groundwater are similar, and that temporal recharge that can cause variations in the $\delta^{18}O$ values is not significant. In addition, the data suggest that there is no significant interbasin recharge occurring because groundwater which can have an out of basin source is similar in $\delta^{18}O$ to stream water generated locally from snow melt.

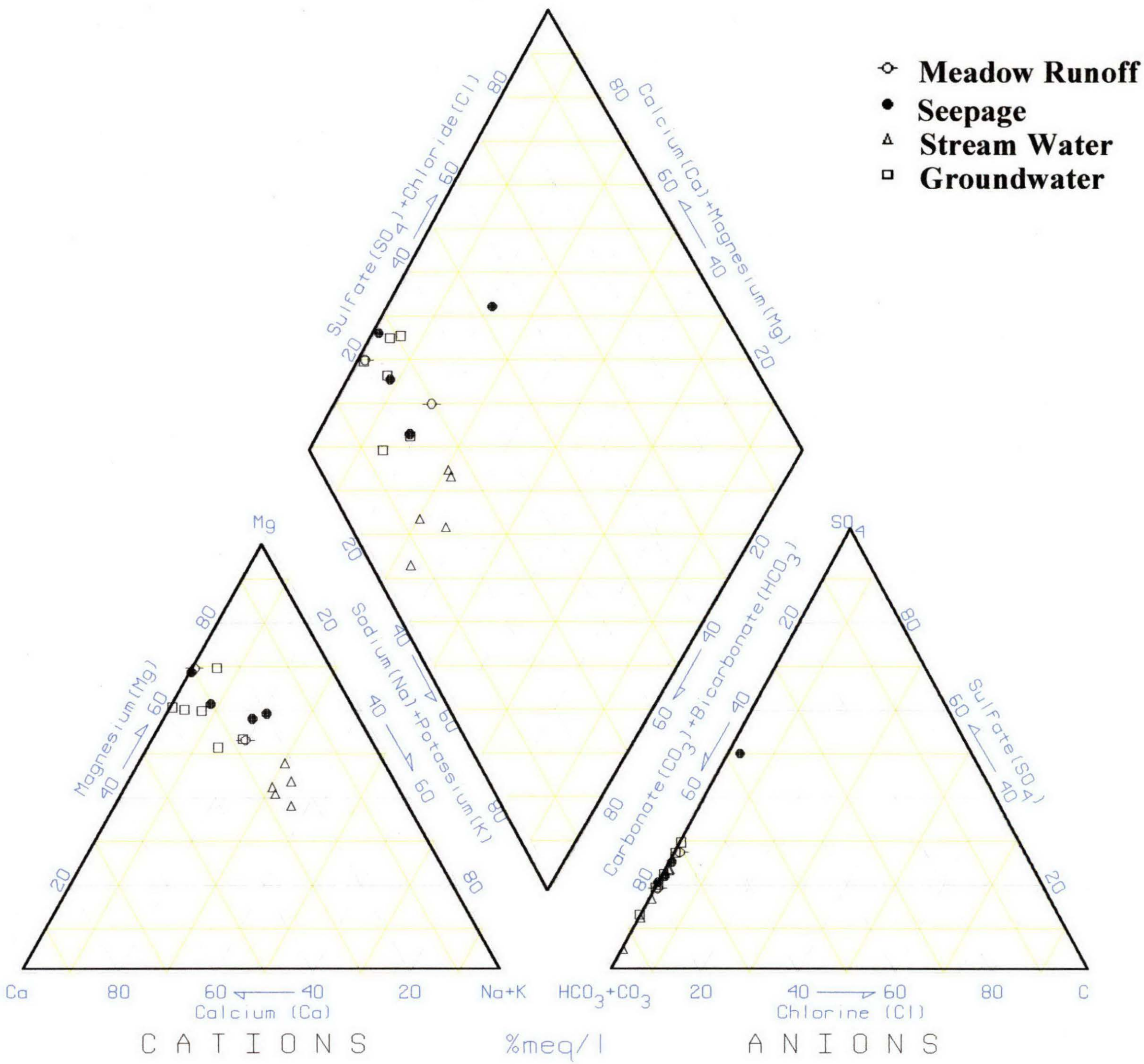


Figure 30. Piper plot of water samples from Big Creek site.

Big Creek: Stable Carbon Isotopic Data

For carbonate aquifers systems, weathering reactions responsible for the major ion chemistry is controlled by soil CO_2. The CO_2 dissolved in water provides the proton (H^+) that initiates carbonate dissolution. Thus coupling DIC and major cations can provide additional insights into the sources of water that maintain wet meadow vegetation.

For samples from Big Creek, we plot the $\delta^{13}C_{DIC}$ vs. Ca/Mg (Figure 31). We use Ca/Mg because these are the major cations produced during weathering reactions in carbonate aquifers. Using an initial $\delta^{13}C$ of soil CO_2 of $-25^0/_{00}$ and accounting for fractionation of $4^0/_{00}$ for CO_2 in soils due to diffusion (Cerling, 1984), the CO_2 that goes into solution and initiates the weathering reaction has a $\delta^{13}C$ value of $-21^0/_{00}$. If this CO_2 reacts with aquifer carbonate with a $\delta^{13}C$ value of $0^0/_{00}$ (assuming marine carbonates), the $\delta^{13}C_{DIC}$ for isotopically evolved groundwater will be about $-11^0/_{00}$ [$\delta^{13}C_{CO2}$ ($-21^0/_{00}$)+$\delta^{13}C_{CARBONATE}$ ($0^0/_{00}$)/2]. The data suggest that as the groundwater evolves (towards more positive $\delta^{13}C_{DIC}$ values), the Ca/Mg ratio decreases. A regression of the groundwater data shows a negative correlation with a good fit (R^2=0.96 at 95% confidence). It is also observed that seeps and meadow runoff at the site lie close to the groundwater trend line, supporting a similar chemical and isotopic evolution. Stream water at the site plots away from this line suggesting a different geochemical evolutionary history. The fact that stream water lies off this trend line, and its position on the plot, suggest that streamflow consists of evolved groundwater (baseflow). As the stream water traverses the site, groundwater addition changes the Ca/Mg ratio with little change in the carbon isotopic value. The major ion chemistry and DIC data suggest that groundwater is the dominant source of water that supports wet meadow vegetation at the Big Creek wet meadow complex.

Corral Canyon: Major Ion Chemistry

Major ion chemistry for Corral Canyon water samples are plotted in Figure 32. The major ion chemistry of water in this basin is influenced by weathering of igneous rocks and can be classified as a Na-K-HCO_3^- geochemical type. The plot shows clustering of seeps/springs known to have a groundwater origin with shallow groundwater and runoff from the wet meadow complex. Thus, the major ion chemistry argues for groundwater as the predominant source for water in the wet meadow complex.

Corral Canyon: Stable Oxygen Isotopes

Stable oxygen ($\delta^{18}O$) isotopic values for Corral Canyon range from -17.9 to -16.5 $^0/_{00}$ for the summer of 1999 (Table 2). The $\delta^{18}O$ values are similar to values reported for this part of the Great Basin (Davisson et al., 1999). Groundwaters, seeps/springs, runoff from the wet meadow complex and stream water show no significant difference in the measured $\delta^{18}O$ as in the case of Big Creek. The data also suggest that the source of water that supply the stream, seeps/springs, meadow runoff and groundwater are similar, and that temporal recharge that can cause variations in the $\delta^{18}O$ values is not significant. As in the case with Big Creek, the data also suggest no significant interbasin recharge from an out of basin groundwater source since the $\delta^{18}O$ of groundwater is similar to stream water generated locally from snow melt.

Corral Canyon: Stable Carbon Isotopic Data

Weathering reactions responsible for the major ion chemistry in igneous rocks is controlled by soil CO_2. The CO_2 dissolved in water dissociates and provides the proton (H^+) that

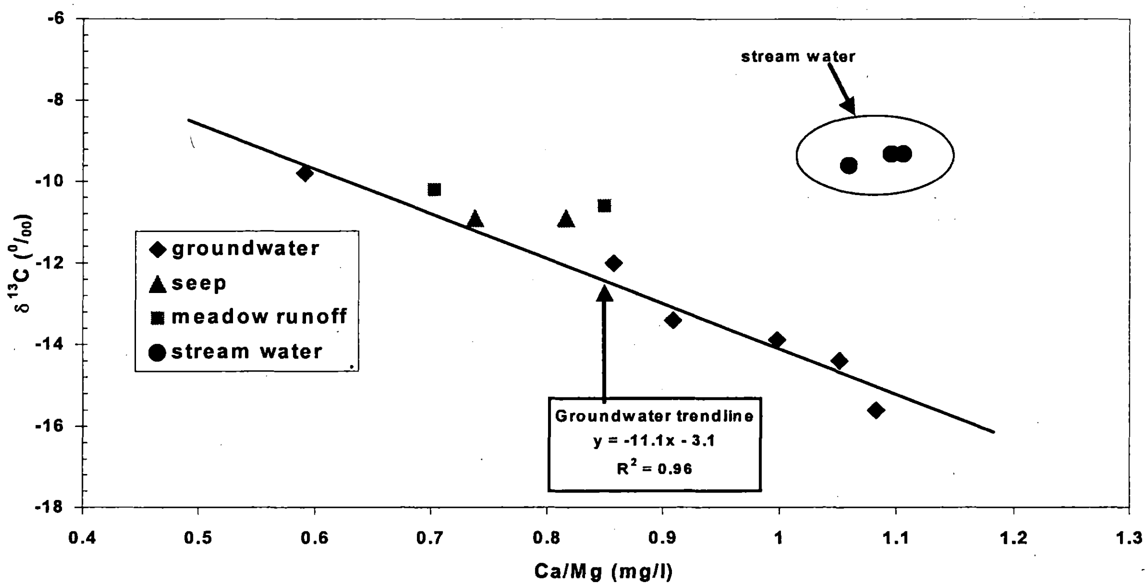


Figure 31. Ca/Mg vs. δ^{13} C_{DIC} for water samples from Big Creek site.

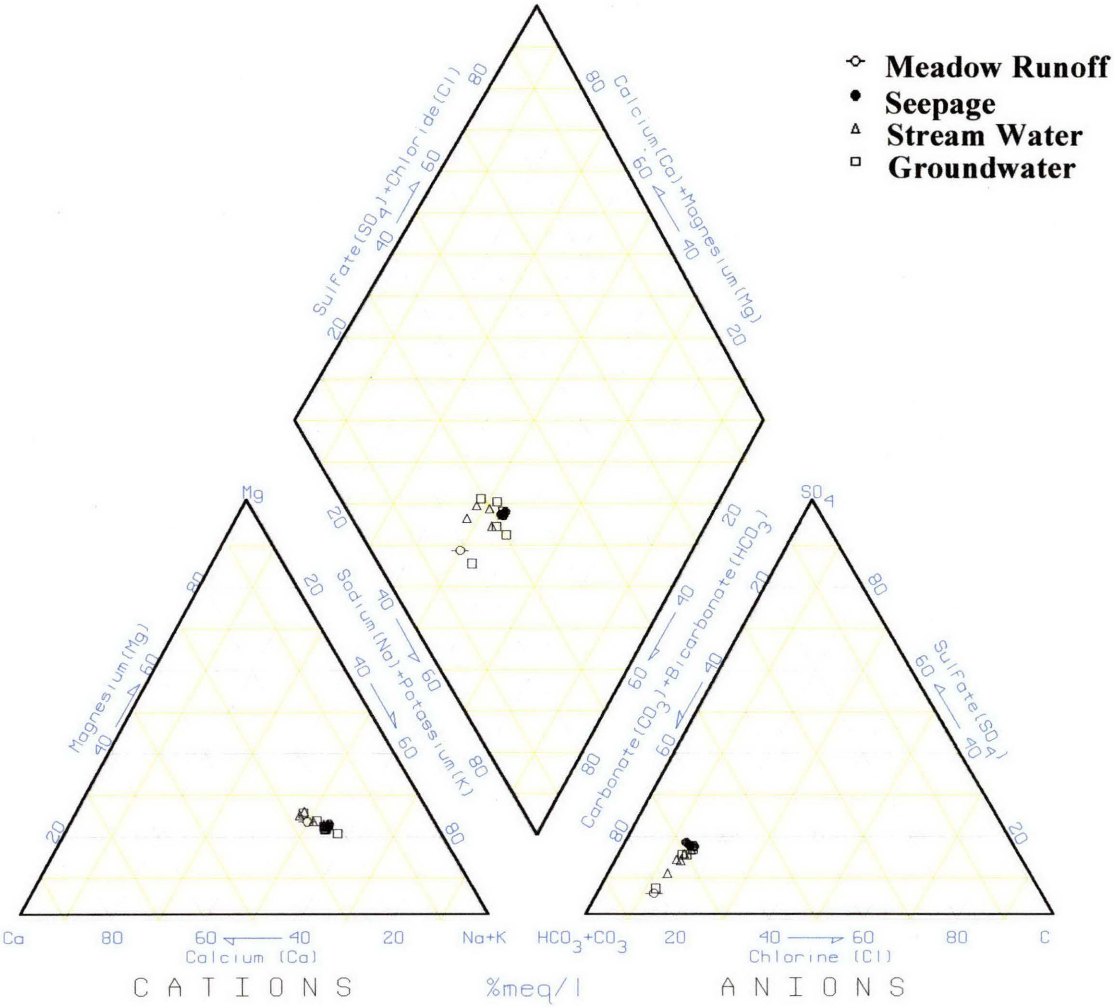


Figure 32. Piper plot of water samples from Corral Canyon site.

initiates hydrolysis in aquifers with igneous rocks. Thus coupling DIC and major cations can provide additional insights into the sources of water that maintain riparian wet meadow vegetation.

The $\delta^{18}C_{DIC}$ vs. Ca/Na for water samples from Corral Canyon is plotted in Figure 33. We use Ca/Na because this ratio is controlled by weathering reactions in igneous aquifers. Using an initial $\delta^{13}C$ of soil CO_2 of $-25^0/_{00}$ and accounting for fractionation of $4^0/_{00}$ for CO_2 in soils due to diffusion (Cerling, 1984), the CO_2 that goes into solution and initiates the weathering reaction has a $\delta^{13}C$ value of $-21^0/_{00}$. As the CO_2 goes into solution, it fractionates by about $1.1^0/_{00}$. If this CO_2 reacts with igneous minerals, there is no contribution to the inorganic carbon. The change in the inorganic carbon isotopic composition arises from the formation of bicarbonate (HCO_3^-). The formation of HCO_3^- from CO_2 can fractionate for up to $9^0/_{00}$ resulting in a final $\delta^{13}C$ values ranging from -19.9 to $10.1^0/_{00}$ for DIC in these systems. The degree of fractionation is thus related to the residence time of water in the aquifer. In other words, more evolved water isotopically undergoes greater fractionation due to longer flow paths. The data shown in Figure 33 suggest that as the groundwater evolves (towards more positive $\delta^{13}C_{DIC}$ values), the Ca/Na ratios increase, showing longer residence time and greater mineral weathering. A regression of the groundwater data shows a positive correlation with a good fit (R^2=0.89 at 95% confidence). It is also observed that some seeps (excluding those in the enclosed rectangle) and meadow runoff at the site lie close to the groundwater trend line, supporting a similar chemical and isotopic evolution. Stream water at the site plots close to this line suggesting a similar geochemical evolutionary history. The effect of snowmelt seen in the Big Creek basin is not evident in Corral Canyon. One stream sample collected immediately above the wet meadow complex is enclosed in the rectangle. As the stream traverses the site, its geochemical character changes significantly and becomes similar to shallow groundwater at the site. As the surface water traverses the site, it is significantly augmented by groundwater recharge causing surface water chemistry to lie along the groundwater trend. The major ion chemistry coupled with DIC data suggest that groundwater is the dominant source of water that support wet meadow vegetation at the Corral Canyon wet meadow complex.

Assessment of Channel Forming Flows

A primary objective of this investigation was to semi-quantitatively determine the instream flows required to maintain channel morphology. An underlying assumption inherent in the existing methodologies for assessing these flow conditions is that the channel is adjusted to the current hydrologic and sedimentologic regime (i.e., the channel is stable). Clearly it would be difficult, if not impossible, to quantitatively determine the magnitude and frequency of channel forming flows along unstable rivers that are continually, and progressively, altering their width, depth, slope, etc.

Recent studies conducted as part of the USDA Ecosystem Management project have demonstrated that most of the axial channels within upland watersheds of central Nevada, including Big Creek and Corral Canyon, are actively incising, and have been for the past several decades (Chambers et al., 1998; Miller et al., in review). Thus, the assumption of channel stability is in error within our study basins, inhibiting a detailed analysis of channel forming flows over timeframes of decades to centuries. Nonetheless, we felt it useful to assess the flow

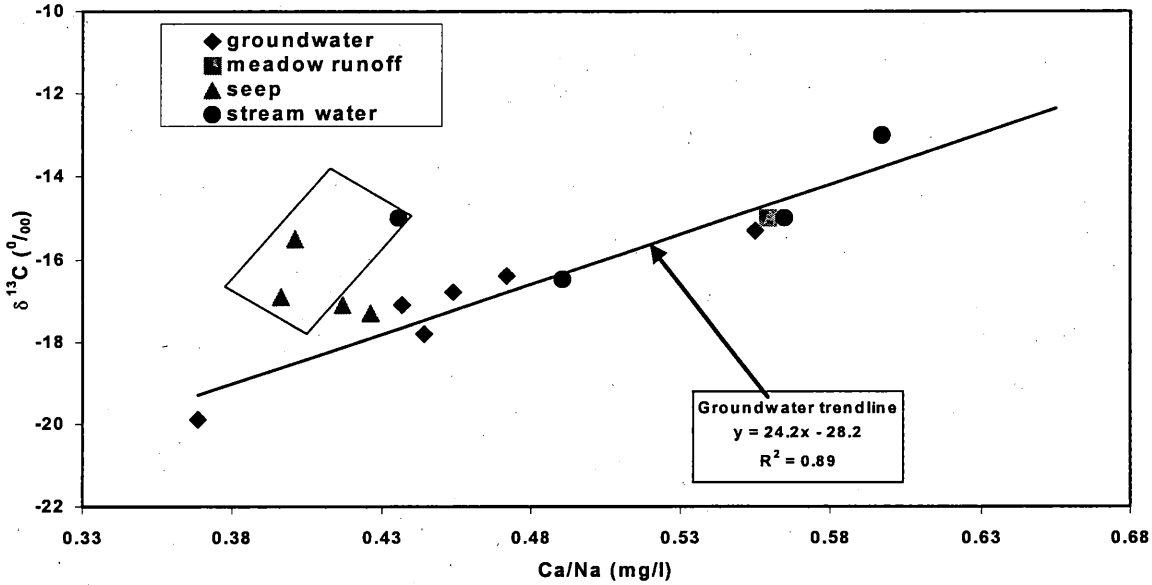


Figure 33. Ca/Na vs. δ^{13} C_{DIC} for water samples from Corral Canyon site.

conditions that are capable of entraining the channel bed material, and that are likely to be responsible for shaping the channel that exists during longer-periods of stream incision. Completion of this analysis involved three steps: (1) a determination of the shear stress required to entrain particles within selected grain-size categories (e.g., D_{50} and D_{84}) using existing selective transport equations, (2) an analysis of the shear stress generated during bankfull conditions at selected locations along Big Creek using the USDA, Forest Service's WinXSPRO analysis system, and (3) a comparison of the shear stress values obtained in steps 1 and 2 to determine the relative magnitude of the flows required to transport particles of a given size.

Estimation of Flow Competence

Flow competence refers to the largest particle a stream can transport under a given set of hydrologic conditions. In recent years, studies of flow competence have become particularly important to the reconstruction of flood flows in both ancient and modern systems in which various empirical relationships are used to determine the flow conditions, particularly depth, required to transport the largest clasts found within the channel bed, or within the deposited flood material (Baker and Ritter, 1975; Costa, 1983). Perhaps one of the most widely used relationships is that of Costa (1983). Compiled from data from a number of different rivers, it relates shear stress during a given flood to the largest-diameter clast that could be entrained by the current. For particles ranging from 1-500 cm, Costa (1983) obtained the following equation:

$$\tau_c = 26.6D^{1.21}$$

where τ_c is the mean-flow shear stress in units of dynes/cm^2, and D is the clast diameter (usually intermediate diameter) in centimeters. Note that the equation essentially provides an estimate of the shear stress required to transport a particle of a given size. In this analysis, the relationship was used to calculate the critical shear stress required to transport particles equal to, or smaller than D_{84} determined at 20 different locations along the channel within the Big Creek study site. The estimated values range from 34 to 46 N/m^2 (Table 3).

Although noting that there is a strong relationship between τ_c and D when data from different rivers are combined, Komar (1987, 1989) argued that the individual data sets (i.e., the data for a given river) follow no statistical trend or may actually run counter to the generally accepted trends. Komar (1989) also argued that where statistical trends do exist for individual rivers, they could be explained by factors associated with selective entrainment of particles within mixed grain-sized deposits. This led him to suggest that equations such as that put forth by Costa (1983) be abandoned in favor of relationships based on the analysis of selective entrainment processes. One possible replacement provided by Komar is:

$$\tau_c = 0.045(\rho_s - \rho)gD_{50}^{0.65}D_i^{0.35}$$

where ρ_s is the density of the particle, ρ is the density of the fluid, g is the gravitational constant, and D_i is the intermediate diameter of the particle to be entrained. Important advantages of this formula is that it accounts for particle density, and the effective of grain-size distribution on entrainment processes.

The estimated shear stress required to transport D_{50} and D_{84} along Big Creek using the Komar equation are provided in Table 3. Estimates associated with D_{84} range from 40 to 53 N/m^2, and are typically higher than those predicted by the equation put forth by Costa (1983).

Estimate of Shear Stress during Bankfull Conditions

Shear stress generated during selected flow conditions can be calculated using the DuBoys equation:

$$\tau = \gamma_f RS,$$

where γ_f is the specific weight of the fluid, R is the hydraulic radius or flow depth, and S is the slope of the water surface. In this analysis, WinXSPRO was used to estimate the shear stress associated with bankfull flows as well as those generated by flows which completely filled the incised trench (referred to here as trenchfull flows). In addition, WinXSPRO allowed for the estimate of bankfull and trenchfull discharge, a parameter that allowed the magnitude of the flows to be compared with previously collected data. The analysis focused only on the Big Creek study area as the lack of an integrated channel prohibited the analysis at the Corral Canyon site.

A significant difficulty that arose during the analysis was the delineation of the bankfull condition along Big Creek within the study area. While this is commonly a difficult task, channel incision, knickpoints, and the existence of one or more small, gravel dominated surfaces within the incised trench at some locations (but not all) made the bankfull channel particularly difficult to delineate along Big Creek (Appendix B). It was ultimately defined at only 8 sites that were characterized by a pronounced, vegetated surface within the incised trench.

The data required to indirectly determine discharge and shear stress with WinXSPRO include channel cross-sectional geometry, water surface gradient, and a flow resistance factor. Cross-sectional geometry was measured in the field using a stadia rod and sag line at 20 locations spaced at approximately 20 m apart along Big Creek. Channel bed gradients were measured over a 40 m reach at each of these sites and was assumed to represent the slope of the water surface. Several resistance factors can be used by WinXSPRO including Manning's roughness coefficient, Jarrett's equation for Manning's roughness coefficient, the Thorne and Zevenbergen's equations (Thorne and Zevenbergen, 1985), and the Neslon et al. (1991) method. Initially we defined resistance using estimated Manning's roughness coefficients determined by visual comparison with Barnes (1968) and by calculating coefficients using the Manning equation for selected sites and times when discharge was measured in the field. For a given discharge, this approach resulted in flow depths that fluctuated wildly from one cross-section to the next, even though the spacing between the cross sections was only about 20 m. In addition, water depths for low flow conditions appeared unreasonably low at some sites. While these fluctuations could be reduced by adjusting the roughness coefficients used at each cross-section, the adjustments were made on a subjective basis. As a result, we replaced the Manning's coefficients with the Thorne and Zevenbergen's resistance equations which are based on an understanding of channel bed material size. These equations are generally applied to channels characterized by gradients that exceed 1 %, are dominated by cobble and boulder bed materials,

and exhibit high relative roughnesses (Thorne and Zevenbergen, 1985), all of which are true along Big Creek within the study area. The use of the Thorne and Zevenbergen resistance equations generated discharge and stage relations that appeared more realistic and less variable, and could be performed without subjectively defining a resistance term for a given cross-section and flow condition. Moreover, discharge values measured in the field at four different sites on two different occasions could be reproduced with less than 30% error.

The shear stress and discharge estimates for bankfull and trenchfull conditions are presented in Table 3. With the exception of the results from cross-section 7, shear stress generated at bankfull flow is well above that required to transport particles equal to or smaller than D_{84} or D_{50} along the entire study reach. At cross section 7, the estimated shear stress at bankfull is equivalent to that required to transport the median sized material in the channel bed (at least as suggested by the selective transport equations). Trenchfull discharge and shear stress estimates are more variable along the channel. Much of this variability is related to the amount of lateral migration that has occurred during incision, a process that results in differences in trench width and flow depths. Nonetheless, trenchfull shear stress values at all 20 cross sections are at least two times greater than the stresses estimated for the transport of particle sizes equivalent to D_{84}. These data suggest that most of the channel bed material can be transported by flows that approximate or are less than bankfull.

A lack of long-term gaging records within the Big Creek basin prohibit a detailed analysis of the recurrence interval of the bankfull flows. It is commonly assumed, however, that bankfull flows occur, on average, about every 2 out of 3 years (Leopold and Wolman, 1957), although these estimates do not apply to all streams, particularly those in mountainous regions with seasonal climatic regimes (such as Big Creek). In addition, the recurrence interval of the bankfull conditions may be influenced within the Big Creek study area by channel incision. Nonetheless, bankfull discharge, and the shear stress thought to be required for the transport of the bed material, were measured in the field from May through July, 1995 by Dr. Michael Amacher (Table 4), and by our group in 1998. During both of these times, incision was observed along the channel, demonstrating that the channel bed material was in transport. Comparison of regional discharge (Figure 34A) and precipitation (Figure 34B) records with those from 1995 and 1998 suggest that the recurrence interval of these spring runoff events is probably less than once every 10 years (possibly much less).

The data presented above strongly suggest that the transport of the coarsest fraction of the channel bed material, and the modification of channel morphology, occurs during bankfull or lesser events that occur rather frequently. This is supported by earlier studies conducted by Chambers et al. (1998) as part of the USDA Ecosystem Management project. They examined and dated gravel dominated surfaces within incised channels of upland watersheds of central Nevada, and found that most of these surfaces were produced during flood flows in 1995, 1983, and one or more events in the 1970's.

Table 3

Comparisons of the Shear Stress Required to Entrain Channel Bed Material with Shear Stress Estimated for Trench Full and Bankfull Flow Conditions at the Big Creek Site. Trench-Full and Bankfull Discharge and Tractive Force Values were Calculated using WinXSPRP.

Cross Section	Critical τ D84 (N/m^2) [a]	Critical τ D50 (N/m^2) [a]	Critical τ D84 (N/m^2) [b]	Trench-Full Q (m^3/s)	Trench-Full τ (N/m^2)	BankFull Q (m^3/s)	Bankfull τ (N/m^2)
1	40	31	34	7.70	223	0.26	66
2	40	31	34	15.68	295	1.32	113
3	46	36	40	12.14	229	---	---
4	53	41	46	1.50	126	0.18	69
5	49	38	43	11.18	306	0.12	41
6	45	34	40	11.62	286	---	---
7	43	31	40	2.74	109	0.17	31
8	40	28	36	3.01	172	---	---
9	46	35	40	3.02	215	.025	89
10	50	41	41	3.54	214	---	---
11	50	39	41	0.78	82	---	---
12	48	38	41	0.75	141	---	---
13	51	41	42	8.44	243	0.45	79
14	53	43	42	3.38	209	---	---
15	51	41	42	2.22	156	---	---
16	48	38	41	0.92	102	---	---
17	50	39	42	1.27	113	---	---
18	51	40	43	1.81	145	---	---
19	48	39	41	4.49	191	0.44	87
20	47	37	39	2.83	178	---	---

a – Based on Equations by Komar (1987)
b – Based on Equations by Costa (1987)

Table 4

Discharge and Shear Stress Data Collected by Mike Amacher (USDA, Rocky Mountain Research Station) along Big Creek in 1995.

Location	Date	Discharge (m^3/s)	Shear Stress (N/m^2)
Campground	5/13/95	0.44	62
Campground	5/26/95	0.71	86
Campground	6/15/95	1.16	92
Campground	7/14/95	1.26	82
Campground	9/14/95	0.26	51
Crossing 1	6/15/95	1.02	89
Crossing 1	7/14/95	0.92	89
Crossing 2	6/16/95	0.59	55
Crossing 2	7/14/95	0.61	65
Crossing 3	6/16/95	0.53	82
Crossing 3	7/14/95	0.36	108
Crossing 4	6/16/95	0.35	84
Crossing 4	7/14/95	0.33	114
Crossing 5	6/16/95	0.31	84
Crossing 5	7/14/95	0.30	132

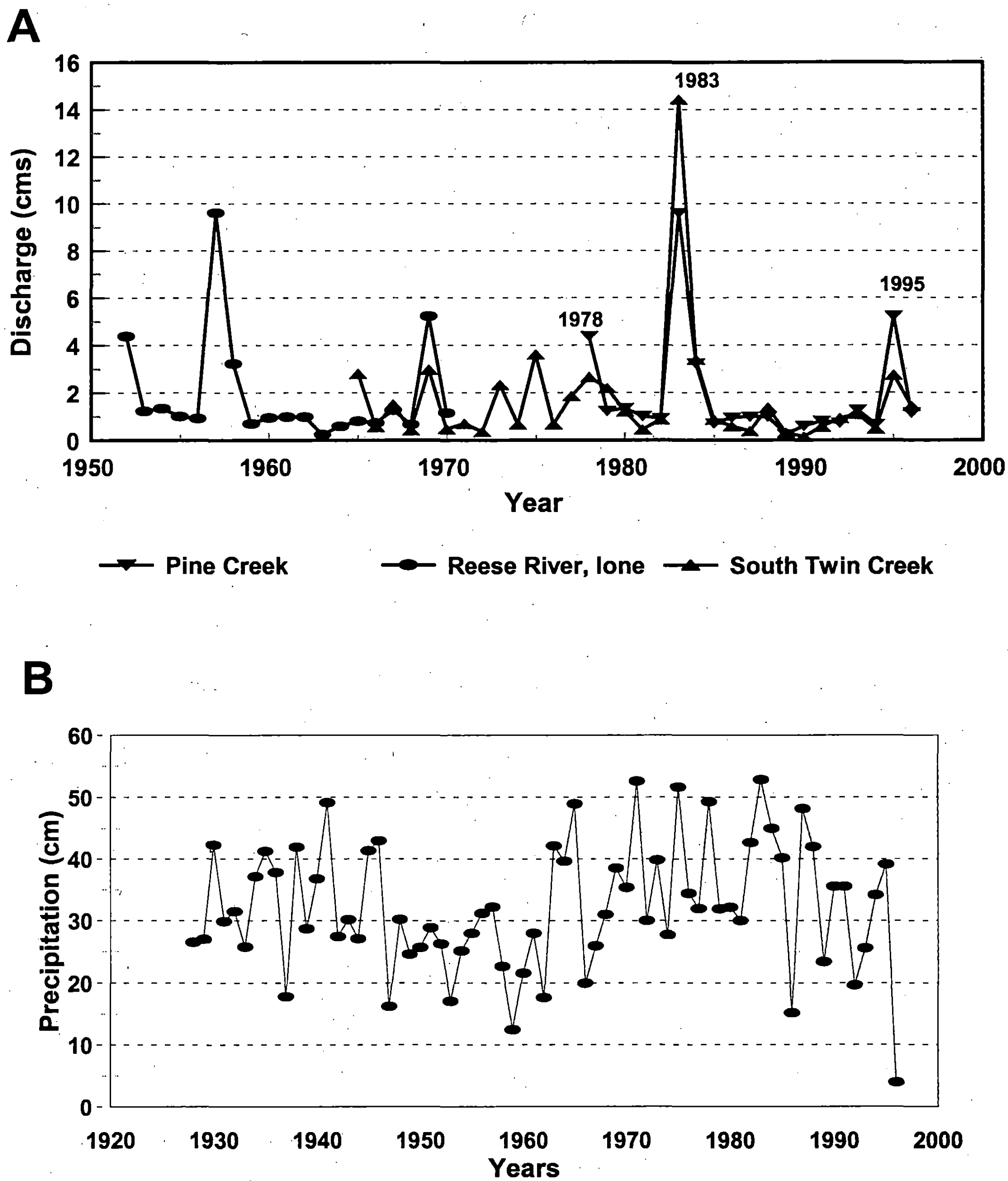


Figure 34. (A) Discharge measurements at selected USGS gaging stations in central Nevada; (B) Annual precipitation at Austin, Nevada. Note scale differences between graphs.

CONCLUSIONS

Field and aerial photographic data demonstrate that nearly all wet meadow complexes occur upstream of side valley alluvial fans. Regional stratigraphic data suggest that meadows have existed in these geomorphic positions for at least the past 4,000 years. However, the morphology of both the meadows and the axial channels were significant modified during a major episode of aggradation that occur from approximately 2,500-1,960 YBP. In particular, the areas were affected by episodes of fan building that temporarily blocked the movement of water and sediment downvalley. More recently, the axial streams located upstream of the side valley fans have been characterized by channel incision and periods of channel avulsion. The net result of these processes has been the development of an extremely complex sequence of stratigraphic deposits upstream of the side valley fans, and which underlie the meadows. These deposits consist of laterally discontinuous alluvial fan materials, axial channel fills, lobate gravel lenses, and fine-grained mineral and peat layers.

At the Big Creek site, a perennial stream traverses the wet meadow and connects upstream with downstream reaches of the axial channel. Immediately upstream of wet meadow areas, water is discharged from the axial channel into the adjacent alluvium. However, farther dowvalley (toward the wet meadow), flow patterns are reversed and water is delivered to the ground surface and the channel from the surrounding alluvium. Shallow groundwater flow (upper 10 m or so) is complicated by the complexity of the local stratigraphy, but is generally downvalley, and along gaining stream reaches, toward the channel. Fluctuations in the water table in areas with wet meadow vegetation are minimal and vertical flow gradients are consistently upward.

The Corral Canyon site differs from the Big Creek site in that it lacks a perennial channel. Moreover, the shallow groundwater flow system is more complex than that observed at the Big Creek site, exhibiting both unconfined and confined flow conditions. The increased complexity in flow patterns can be partly attributed to the nature of the valley fill deposits, particularly the occurrence of fine-grained layers that result in locally confined flow conditions. Moreover, the groundwater system receives more subsurface input of water from side valley alluvial fan deposits. Groundwater flow in the area is similar to the Big Creek site in that water table (and potentiometric surface) fluctuations are minimal in areas of wet meadow vegetation, and vertical flow gradients are consistently upward.

At both sites, groundwater flow patterns, geochemical data, and seismic surveys suggest that the primary source of water to the meadow is water moving downvalley through the alluvial valley fill that is forced to the surface by constrictions in the width and/or thickness of the alluvial aquifer. Preliminary data suggest that a principal reduction in the cross-sectional area of the alluvial aquifer is due to bedrock highs beneath the valley fill that reduce aquifer thicknesses. These bedrock highs appear to correspond to large, side valley fans, explaining the consistent occurrence of wet meadows upstream of fan complexes. We hypothesize that the alluvial fan deposits covered and protected the underlying bedrock from erosion during previous (perhaps pre-Holocene?) valley cutting.

An underlying assumption inherent in the existing methodologies for assessing the instream flow conditions required to maintain channel form is that the channel is adjusted to the

current hydrologic and sedimentologic regime (i.e., the channel is stable). Most of the axial streams (including Big Creek) within the upland basins of central Nevada are incising during major runoff events (e.g., 1983, 1995). As a result, it was not possible to accurately determine the instream flows needed to sustain channel morphology for the field sites examined in this investigation. However, an analysis of particle entrainment suggests that relatively frequent flows (occurring once every five to ten years) are capable of effectively shaping the channel bed and bank materials.

Studies of other streams in the western U.S. suggest that channel entrenchment may result in a lowering of water table levels and a change in riparian plant communities. A continuous supply of water to the wet meadows from upvalley alluvial valley aquifers suggests that the affects of channel cutting on water table levels may be minimal at the sites examined in this study. However, it is important to recognize that the impacts of entrenchment on the shallow groundwater flow systems are poorly understood and should be more extensively examined using numerical modeling approaches that examine the potential changes in the groundwater flow system as water levels in the channel are lowered in association with channel cutting. In addition, because the alluvial valley fill may be the primary source of water to the wet meadows, the meadow complexes may be significantly impacted by shallow groundwater withdrawals located significant distances from the meadow sites. Thus, assessment of the potential impacts of water diversions on these ecosystems is likely to require a watershed scale, mass balance approach.

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APPENDIX A
Piezometer and Well Specifications and Elevation Data

Table A-1: Well specifications for Big Creek

Well #	Slotting (cm)	Depth (cm)	Stick-up (cm)
1	100.0	245.8	59.0
2	100.0	627.3	61.5
3	100.0	382.6	71.0
4	50.0	248.8	56.0
5	100.0	511.8	59.0
6	100.0	765.6	75.0
7	100.0	630.1	72.5
8	0.0	495.7	68.5
9	50.0	107.6	65.5
10	100.0	273.6	25.5
11	0.0	339.1	71.0
12	0.0	269.1	21.0
13	75.0	237.8	67.0
14	75.0	235.8	69.0
15	0.0	262.3	28.5
16	0.0	227.1	67.5
17	50.0	223.6	68.5
18	50.0	223.6	68.5
19	0.0	115.6	69.0
20	50.0	227.1	67.5
21	50.0	211.6	71.2
22	50.0	237.8	67.0
23	0.0	237.1	66.5
24	50.0	237.8	67.0
25	50.0	227.1	67.5
26	30.0	50.5	58.0
27	0.0	56.7	63.3
28	0.0	229.2	65.4
29	0.0	235.9	58.0
30	100.0	304.8	69.8
31	50.0	227.6	67.0
32	50.0	140.8	70.6
33	0.0	225.1	69.5
34	0.0	226.6	68.0
35	50.0	226.6	68.0
36	50.0	200.6	69.0
37	50.0	83.8	57.0
38	50.0	198.6	70.0
39	50.0	102.5	67.5
40	50.0	135.6	67.0

Well #	Slotting (cm)	Depth (cm)	Stick-up (cm)
41	50.0	201.8	64.4
42	50.0	133.3	67.5
43	70.0	229.6	65.0
44	0.0	118.5	31.5
45	0.0	227.1	67.5
46	50.0	108.8	68.2
47	0.0	212.6	70.0
48	50.0	159.3	68.5
49	0.0	226.6	68.0
50	0.0	234.4	60.2
51	100.0	522.8	57.0
52	50.0	227.8	64.3
53	0.0	50.0	66.0
54	0.0	464.8	50.0
MW-2	30.0	124.0	76.0
MW-24	50.0	70.0	69.5
MW-26	50.0	71.0	65.8
MW-3	30.0	180.0	91.3
MW-32	50.0	54.0	70.3
MW-4	50.0	159.0	60.0
MW-5	50.0	128.0	53.7

Table A-2: Well Specifications for Corral Canyon

Well #	Slotting (cm)	Depth (cm)	Stick-up
1	100.0	529.6	61.2
2	100.0	356.6	97.0
3	100.0	564.6	117.5
4	100.0	580.1	73.5
5	100.0	549.1	57.0
6	100.0	289.6	13.0
7	100.0	618.5	39.5
8	100.0	473.7	69.5
9	100.0	293.8	11.0
10	100.0	280.3	24.5
11	100.0	478.1	66.0
12	100.0	540.7	65.3
13	100.0	442.1	57.0
14	100.0	327.8	85.0
15	100.0	275.6	18.5
16	100.0	236.2	67.0
17	100.0	304.8	80.5
18	100.0	236.2	67.0
19	100.0	531.1	73.5
20	100.0	304.8	59.0
21	100.0	304.8	64.0
22	50.0	175.9	70.5
23	50.0	129.0	92.0
24	50.0	164.3	66.8
25	100.0	304.8	82.0
26	100.0	304.8	76.0
27	100.0	237.3	67.5
28	50.0	156.9	71.7
29	100.0	386.1	66.5
30	100.0	408.9	42.0
31	100.0	304.8	12.5
32	100.0	304.8	81.0
33	100.0	304.8	47.6
34	100.0	539.5	65.0
35	100.0	329.6	49.5
36	100.0	403.9	50.8
37	100.0	304.8	70.0
38	100.0	227.3	14.0
39	50.0	185.4	67.5

Well #	Slotting (cm)	Depth (cm)	Stick-up
41	100.0	304.8	46.5
42	100.0	304.8	47.0
44	100.0	270.8	34.0
45	50.0	117.4	34.0
46	50.0	93.4	53.5
47	50.0	121.4	31.0
48	50.0	117.4	35.0
49	50.0	181.8	123.0
51	100.0	262.5	41.0
52	100.0	225.3	79.5
53	50.0	203.2	96.5
54	50.0	109.9	42.5
55	50.0	86.4	66.0
56	50.0	194.6	49.5
57	50.0	73.9	78.5
58	50.0	89.4	63.0
59	100.0	233.5	70.0
60	100.0	338.7	24.5
61	100.0	272.3	32.5
62	100.0	357.3	37.0
63	100.0	355.5	49.0
64	100.0	373.7	81.0
65	50.0	106.4	46.0
3a	50.0	121.9	67.0
4a	50.0	125.4	60.5
5a	100.0	401.4	78.0
62a	50.0	104.7	47.7

Table A-3: Corral Canyon Piezometer Elevation Comparison

Well #	Elevation (m) Site 1	Well #	Elevation (m) Site 2	Comparison
1	11.53	1	11.53	0.00
2	10.87	2	10.89	-0.02
5	10.49	5	10.49	0.00
5A	10.60	5A	10.60	0.00
6	9.52	6	9.48	0.04
10	7.61	10	7.58	0.03
13	6.67	13	6.65	0.02
14	6.14	14	6.15	-0.01
15	6.22	15	6.22	0.00
16	5.92	16	5.91	0.01
17	5.94	17	5.95	-0.01
18	5.84	18	5.86	-0.02
19	4.86	19	4.86	0.00
20	3.92	20	3.91	0.00
22	3.01	22	3.01	0.00
23	2.74	23	2.75	-0.01
24	2.98	24	2.99	-0.01
25	2.81	25	2.81	0.00
26	1.43	26	1.43	0.00
28	0.88	28	0.87	0.01
30	1.45	30	1.46	-0.01
32	0.11	32	0.07	0.04
34	-0.31	34	-0.30	-0.01
36	0.61	36	0.62	-0.01
38	-1.39	38	-1.42	0.03
42	-1.81	42	-1.75	-0.06
44	-1.43	44	-1.41	-0.02
46	-3.28	46	-3.21	-0.07
48	-3.29	48	-3.27	-0.02
52	-5.14	52	-5.15	0.01
54	-5.19	54	-5.16	-0.03
56	-5.31	56	-5.33	0.02
58	-5.51	58	-5.48	-0.03
60	-5.81	60	-5.81	0.00
Average of Absolute Difference				0.02

Note: Elevational reference differs from that which was used to construct potentiometric surface maps and cross-sections.

Table A-4: Big Creek Piezometer Elevation Comparison

Well #	Elevation (m) Site 1	Well #	Elevation (m) Site 2	Comparison
6	-4.15	6	-4.13	0.02
8	-5.16	8	-5.17	-0.01
9	-12.21	9	-12.19	0.02
10	-11.74	10	-11.76	-0.02
11	-11.74	11	-11.76	-0.02
12	-11.74	12	-11.76	-0.02
15	-14.02	15	-14.05	-0.03
17	-14.96	17	-14.94	0.02
18	-14.58	18	-14.57	0.01
19	-13.79	19	-13.77	0.02
20	-15.19	20	-15.19	0.00
21	-16.21	21	-16.21	0.00
23	-15.56	23	-15.53	0.03
25	-15.44	25	-15.41	0.03
26	-15.88	26	-15.85	0.02
27	-15.88	27	-15.85	0.02
28	-15.88	28	-15.85	0.02
29	-15.85	29	-15.81	0.04
30	-16.88	30	-16.87	0.00
31	-16.60	31	-16.58	0.02
32	-16.35	32	-16.35	0.00
33	-15.82	33	-15.81	0.01
35	-17.54	35	-17.54	0.00
36	-18.28	36	-18.25	0.03
37	-18.87	37	-18.85	0.02
38	-18.54	38	-18.51	0.03
51	-9.16	51	-9.16	0.00
52	-16.03	52	-16.00	0.03
MW26	-15.88	MW26	-15.85	0.02
MW3	-18.03	MW3	-18.01	0.01
Average of Absolute Difference				

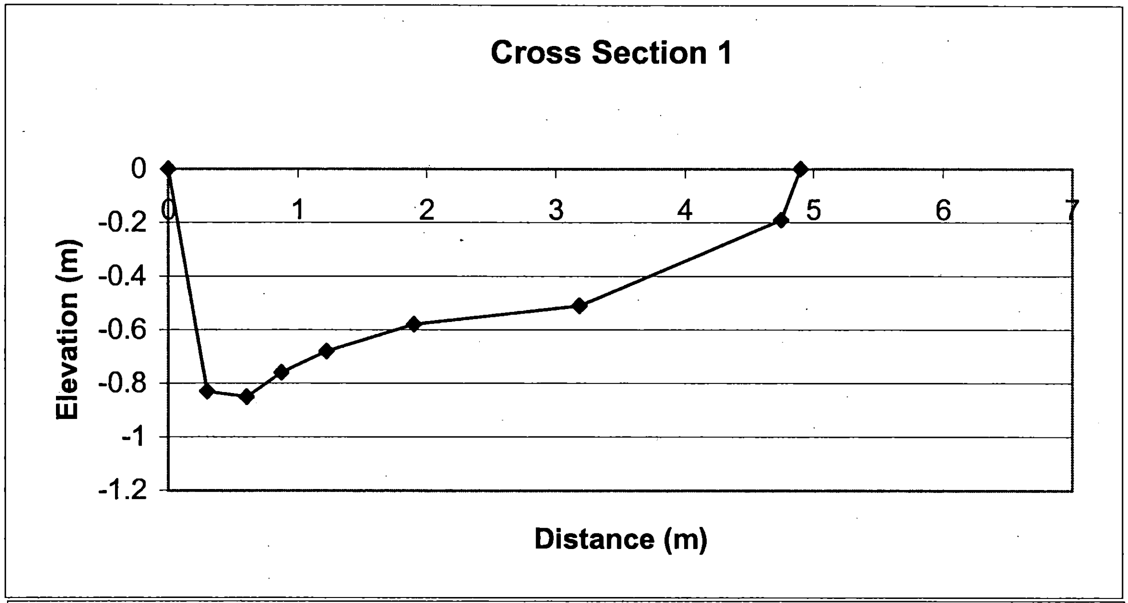
Note: Elevational reference differs from that which was used to construct potentiometric surface maps and cross-sections.

APPENDIX B
Channel Cross-Section Data

X-Section 1

Distance(m)	Elevation(m)
4.9	0
4.75	-0.19
3.18	-0.51
1.9	-0.58
1.22	-0.68
0.87	-0.76
0.6	-0.85
0.3	-0.83
0	0

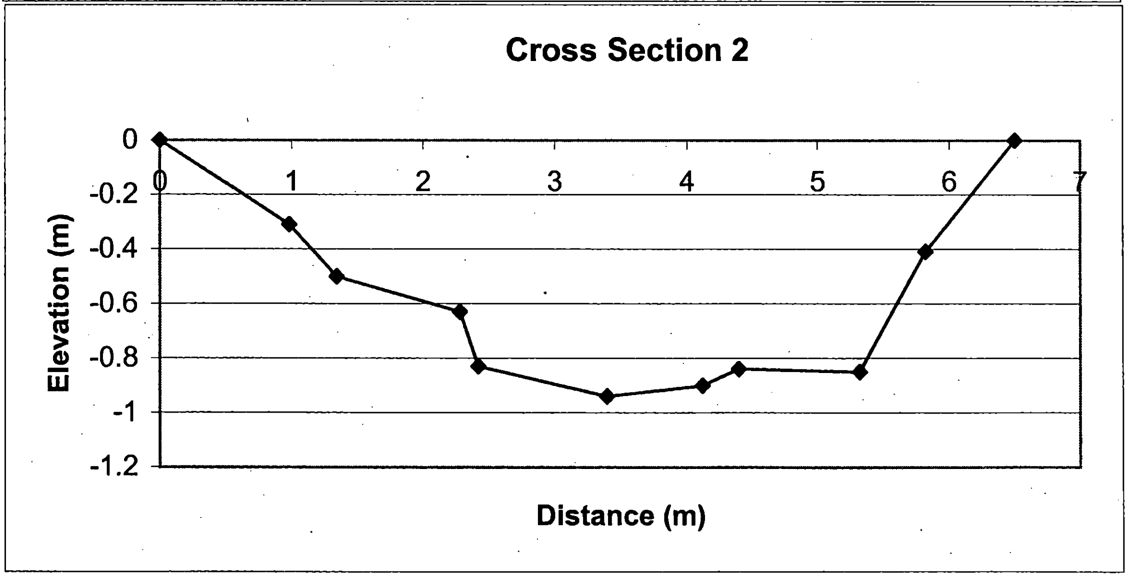
Slope	0.055
D50 (mm)	42
D84 (mm)	82



X-Section 2

Distance(m)	Elevation(m)
6.5	0
5.82	-0.41
5.32	-0.85
4.4	-0.84
4.12	-0.9
3.39	-0.94
2.42	-0.83
2.28	-0.63
1.34	-0.5
0.98	-0.31
0	0

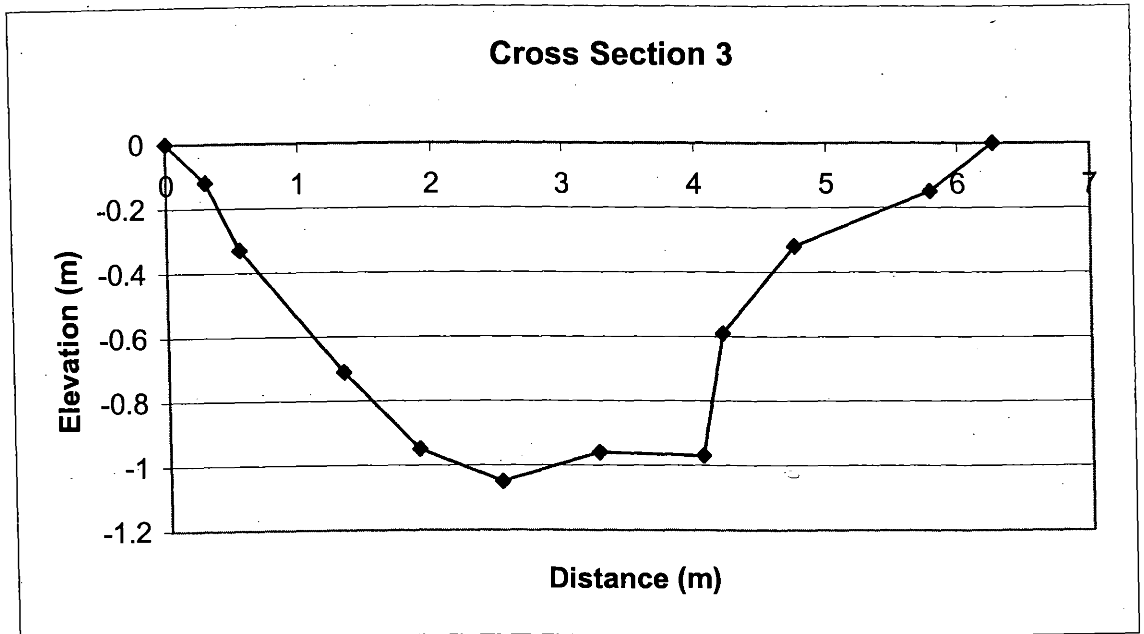
Slope	0.055
D50 (mm)	42
D84 (mm)	82



X-Section 3

Distance (m)	Elevation(m)
6.27	0
5.79	-0.15
4.75	-0.32
4.2	-0.59
4.04	-0.97
3.25	-0.96
2.51	-1.05
1.88	-0.95
1.32	-0.71
0.55	-0.33
0.3	-0.12
0	0

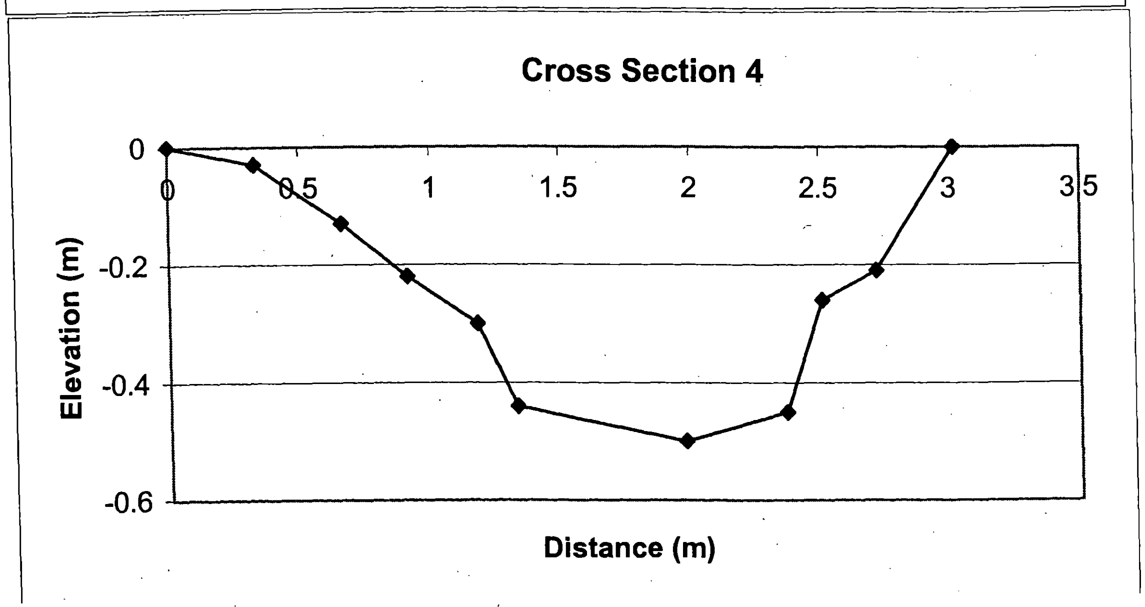
Slope	0.045
D50 (mm)	49
D84 (mm)	94



X-Section 4

Distance (m)	Elevation(m)
3.02	0
2.72	-0.21
2.51	-0.26
2.37	-0.45
1.98	-0.5
1.33	-0.44
1.18	-0.3
0.91	-0.22
0.66	-0.13
0.33	-0.03
0	0

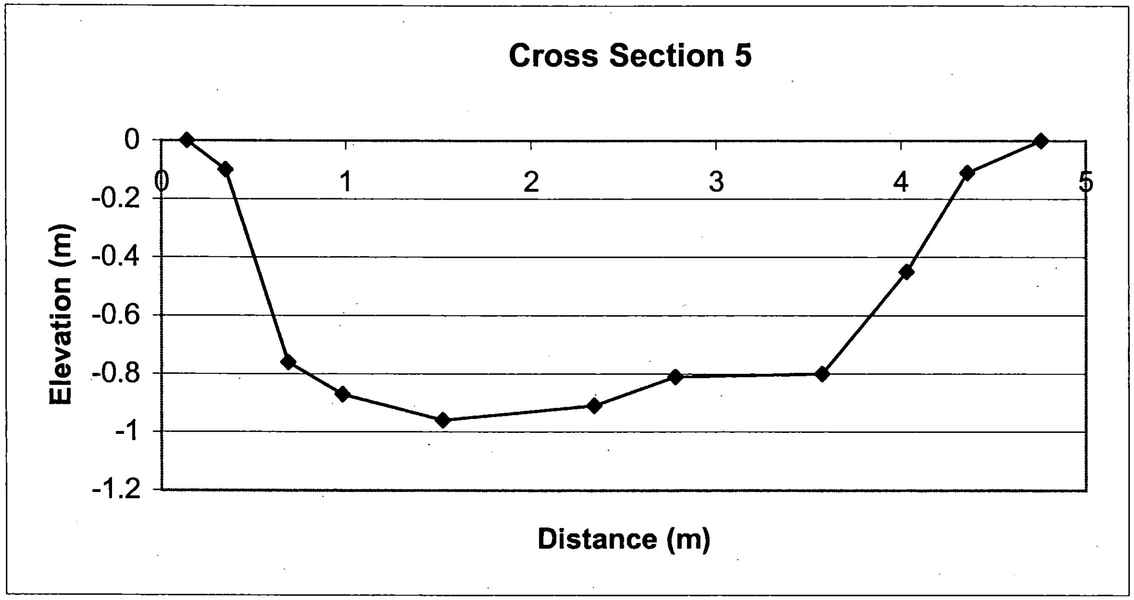
Slope	0.0525
D50 (mm)	56
D84 (mm)	106



X-Section 5

Distance (m)	Elevation(m)
4.76	0
4.36	-0.11
4.03	-0.45
3.57	-0.8
2.78	-0.81
2.34	-0.91
1.52	-0.96
0.98	-0.87
0.69	-0.76
0.35	-0.1
0.14	0

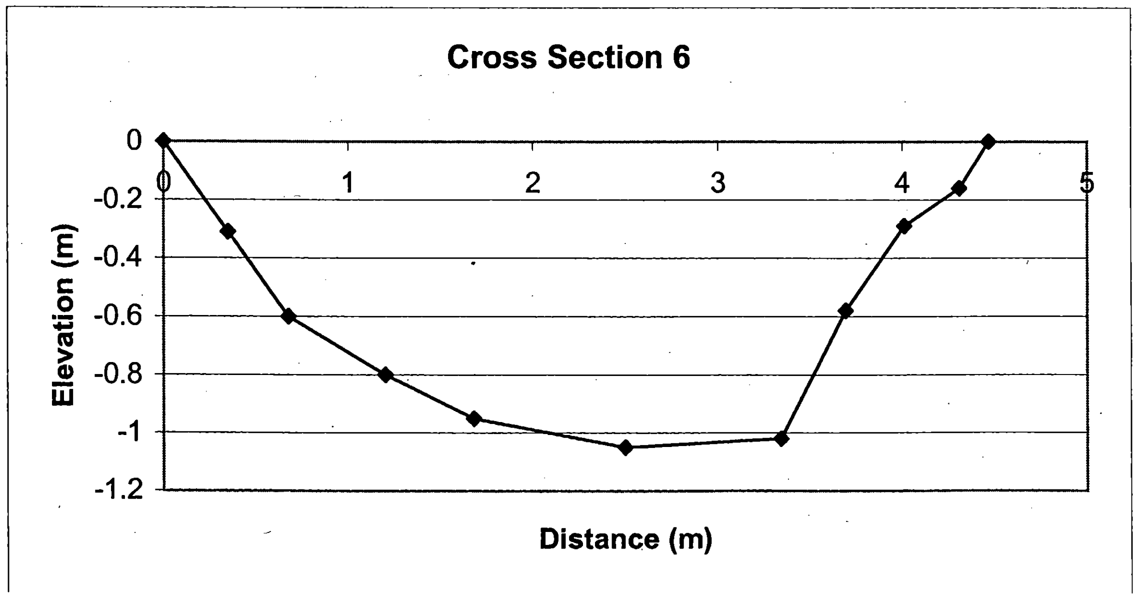
Slope	0.0563
D50 (mm)	52
D84 (mm)	100



X-Section 6

Distance (m)	Elevation(m)
4.47	0
4.31	-0.16
4.01	-0.29
3.69	-0.58
3.34	-1.02
2.5	-1.05
1.68	-0.95
1.2	-0.8
0.68	-0.6
0.35	-0.31
0	0

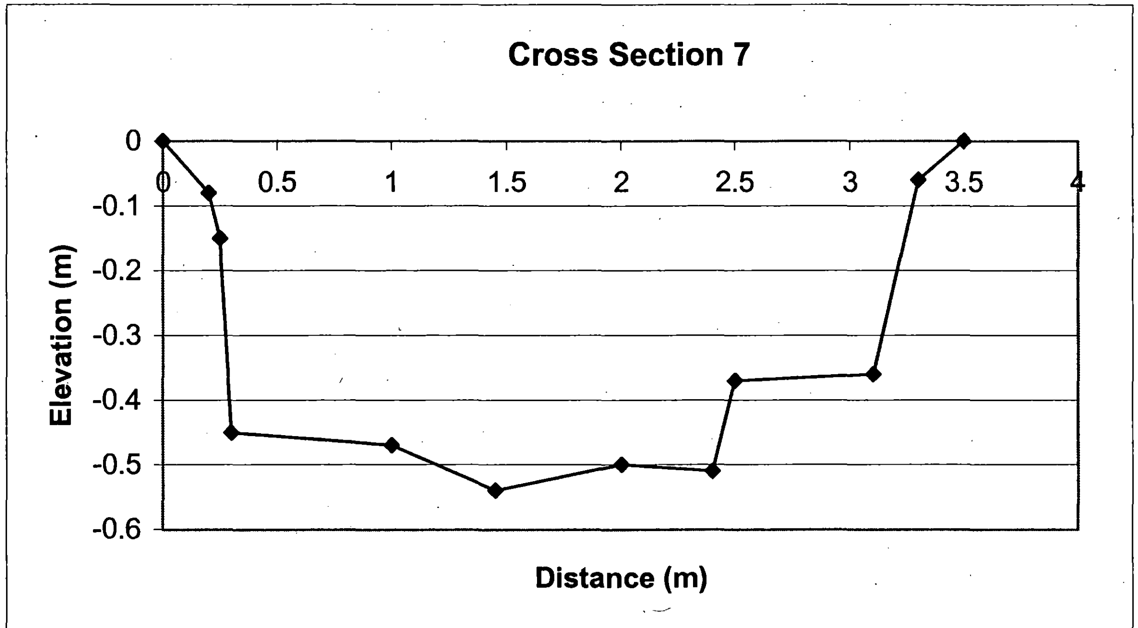
Slope	0.05
D50 (mm)	47
D84 (mm)	94



X-Section 7

Distance (cm)	Elevation(m)
0	0
0.2	-0.08
0.25	-0.15
0.3	-0.45
1	-0.47
1.45	-0.54
2	-0.5
2.4	-0.51
2.5	-0.37
3.1	-0.36
3.3	-0.06
3.5	0

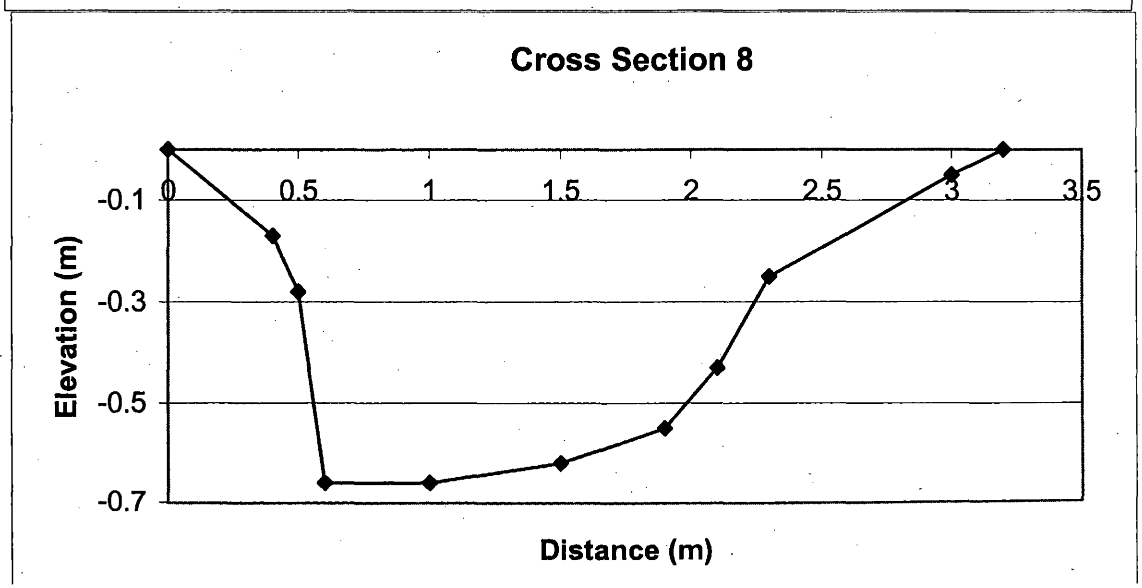
Slope	0.0325
D50 (mm)	43
D84 (mm)	94



X-Section 8

Distance (m)	Elevation(m)
0	0
0.4	-0.17
0.5	-0.28
0.6	-0.66
1	-0.66
1.5	-0.62
1.9	-0.55
2.1	-0.43
2.3	-0.25
3	-0.05
3.2	0

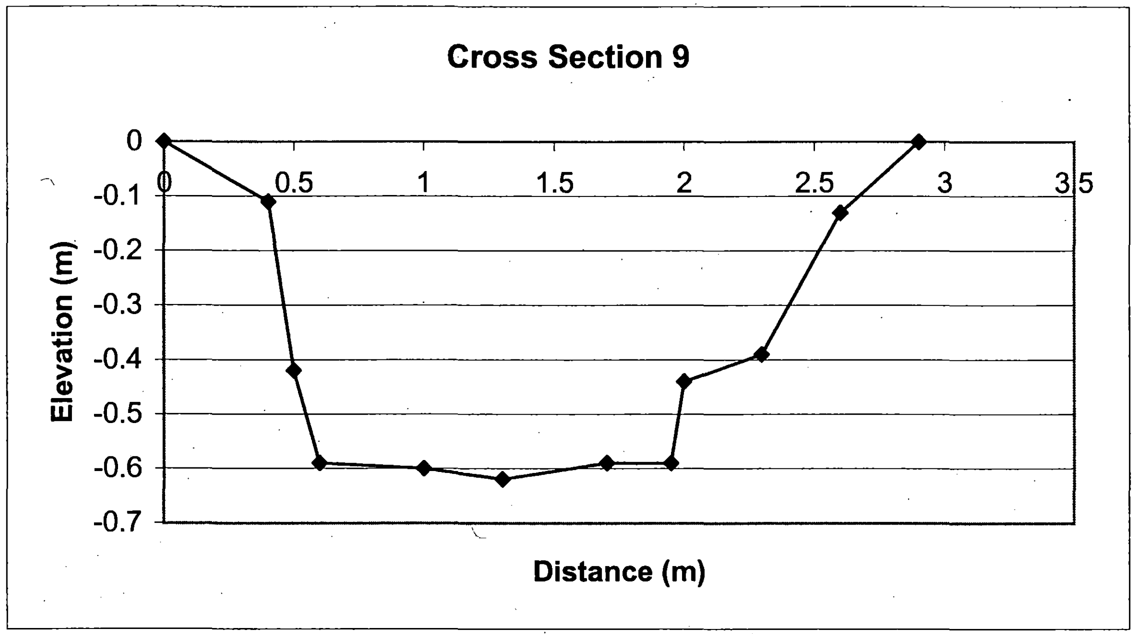
Slope	0.055
D50 (mm)	39
D84 (mm)	93



X-Section 9

Distance (m)	Elevation(m)
0	0
0.4	-0.11
0.5	-0.42
0.6	-0.59
1	-0.6
1.3	-0.62
1.7	-0.59
1.95	-0.59
2	-0.44
2.3	-0.39
2.6	-0.13
2.9	0

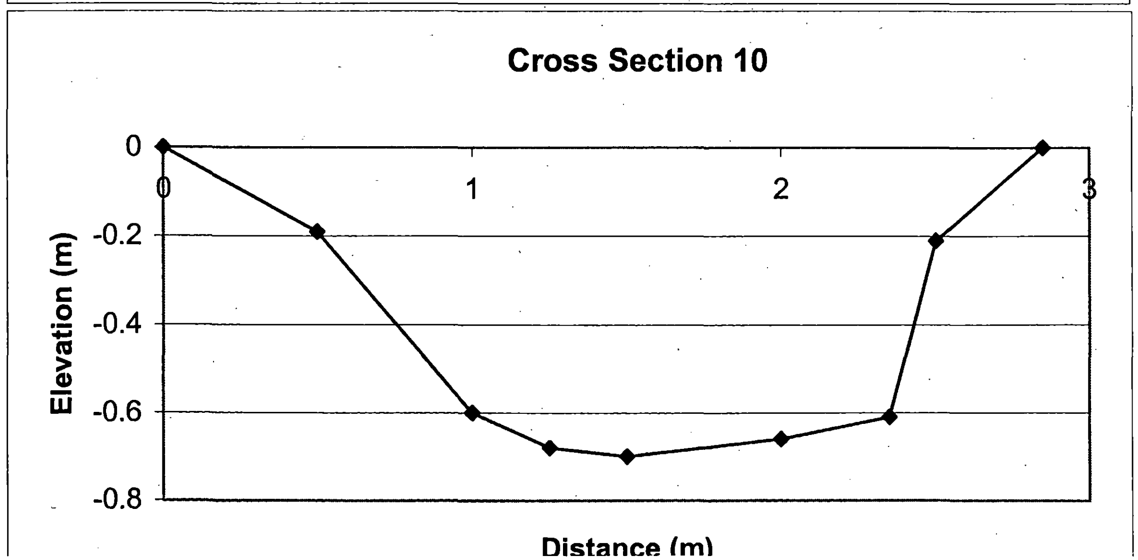
Slope	0.0675
D50 (mm)	48
D84 (mm)	94



X-Section 10

Distance (m)	Elevation(m)
0	0
0.5	-0.19
1	-0.6
1.25	-0.68
1.5	-0.7
2	-0.66
2.35	-0.61
2.5	-0.21
2.85	0

Slope	0.0613
D50 (mm)	56
D84 (mm)	95

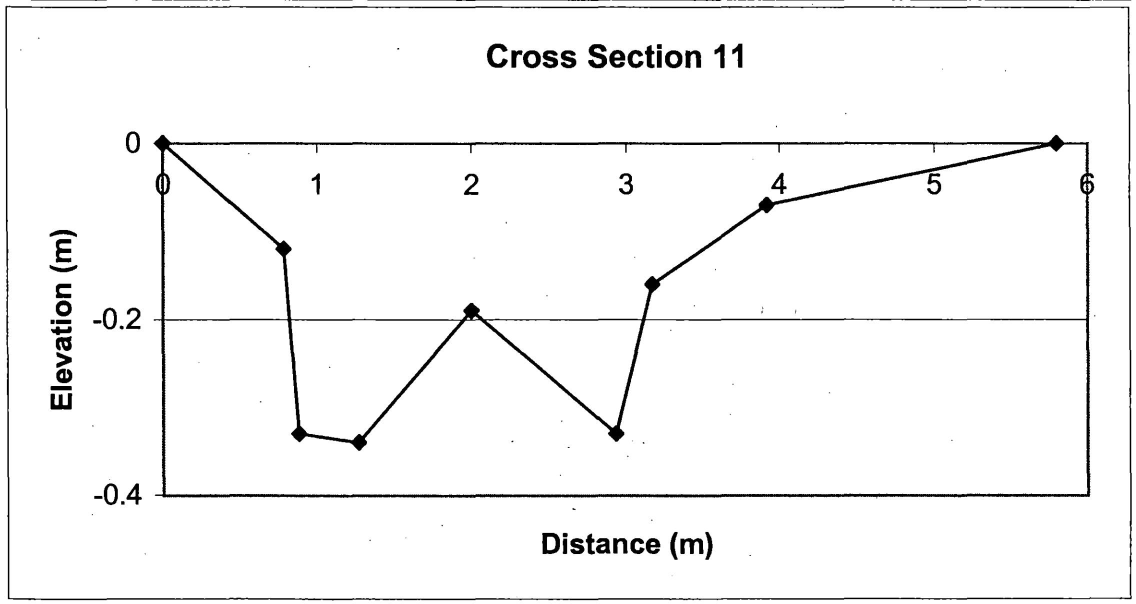


Distance (m)

X-Section 11

Distance (m)	Elevation(m)
5.8	0
3.92	-0.07
3.17	-0.16
2.93	-0.33
2	-0.19
1.27	-0.34
0.88	-0.33
0.78	-0.12
0	0

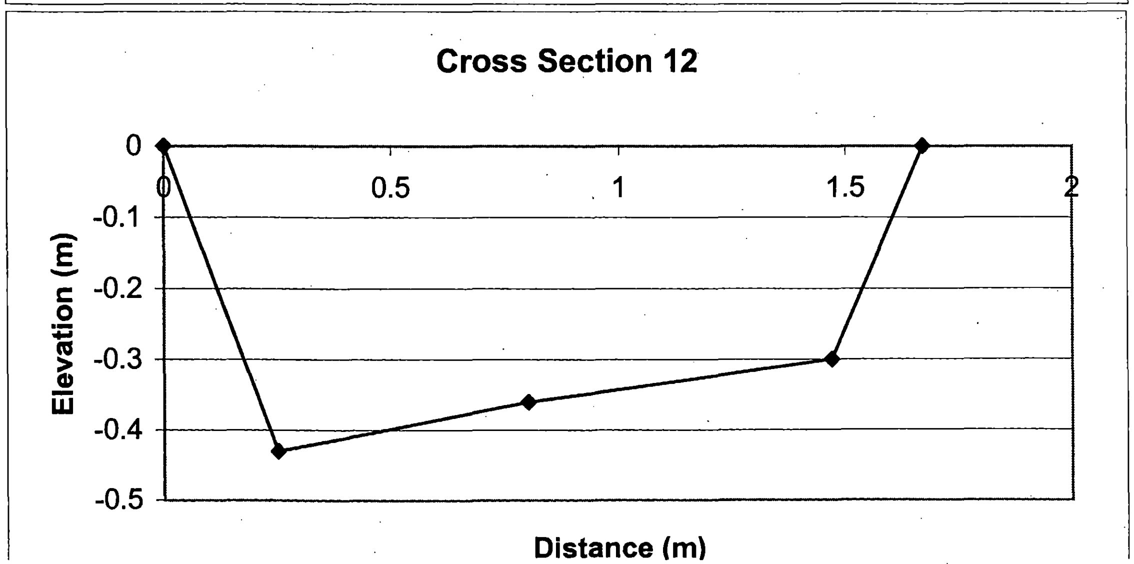
Slope	0.0613
D50 (mm)	54
D84 (mm)	96



X-Section 12

Distance (m)	Elevation(m)
1.67	0
1.47	-0.3
0.8	-0.36
0.25	-0.43
0	0

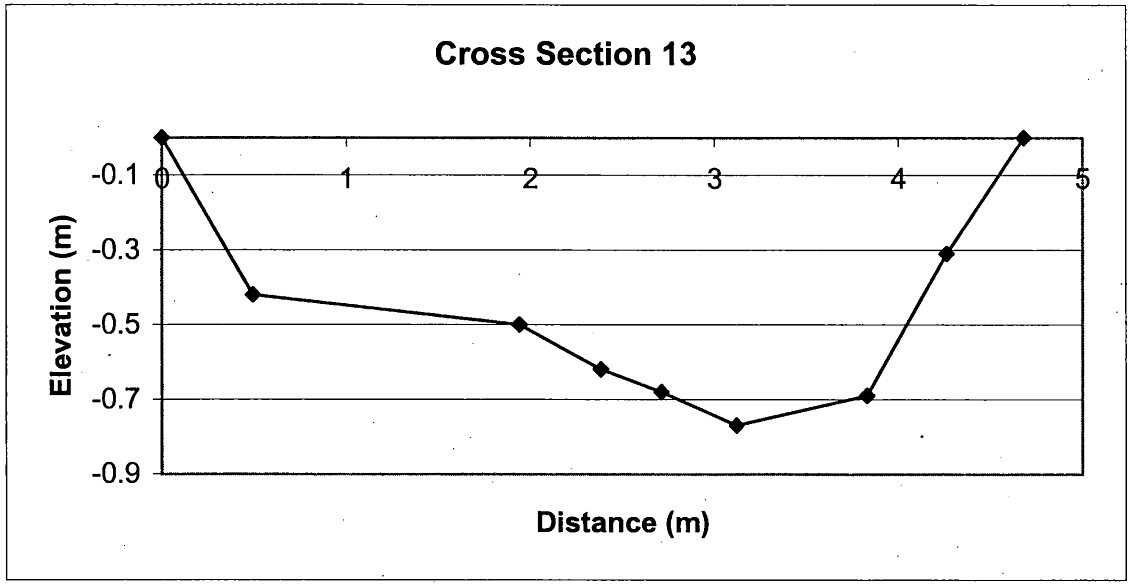
Slope	0.0663
D50 (mm)	52
D84 (mm)	96



X-Section 13

Distance (m)	Elevation(m)
0	0
0.49	-0.42
1.94	-0.5
2.38	-0.62
2.71	-0.68
3.12	-0.77
3.83	-0.69
4.26	-0.31
4.68	0

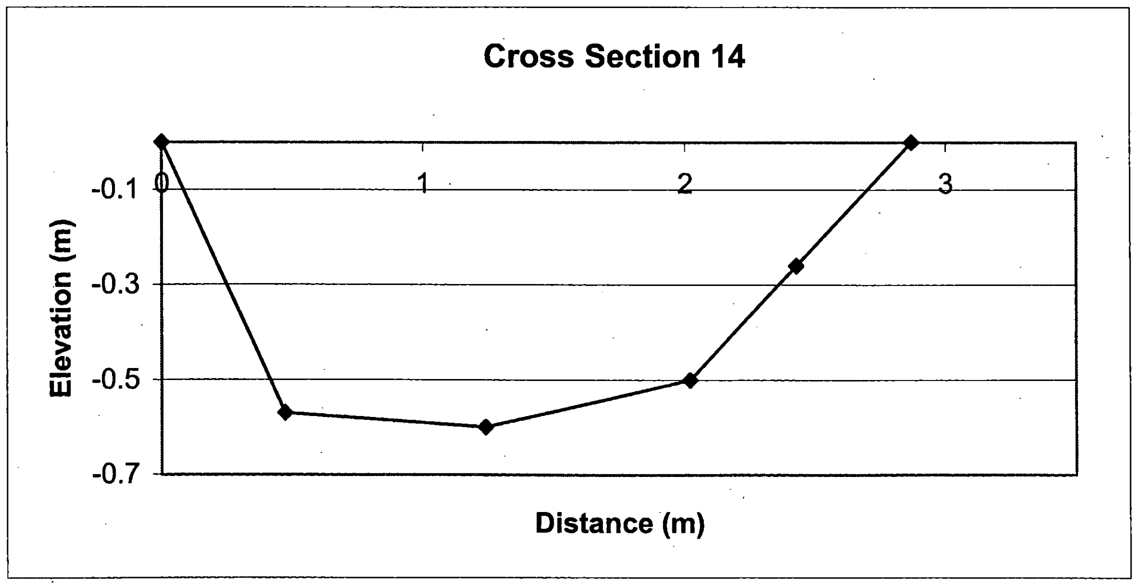
Slope	0.0525
D50 (mm)	56
D84 (mm)	97



X-Section 14

Distance (m)	Elevation(m)
2.87	0
2.43	-0.26
2.02	-0.5
1.24	-0.6
0.47	-0.57
0	0

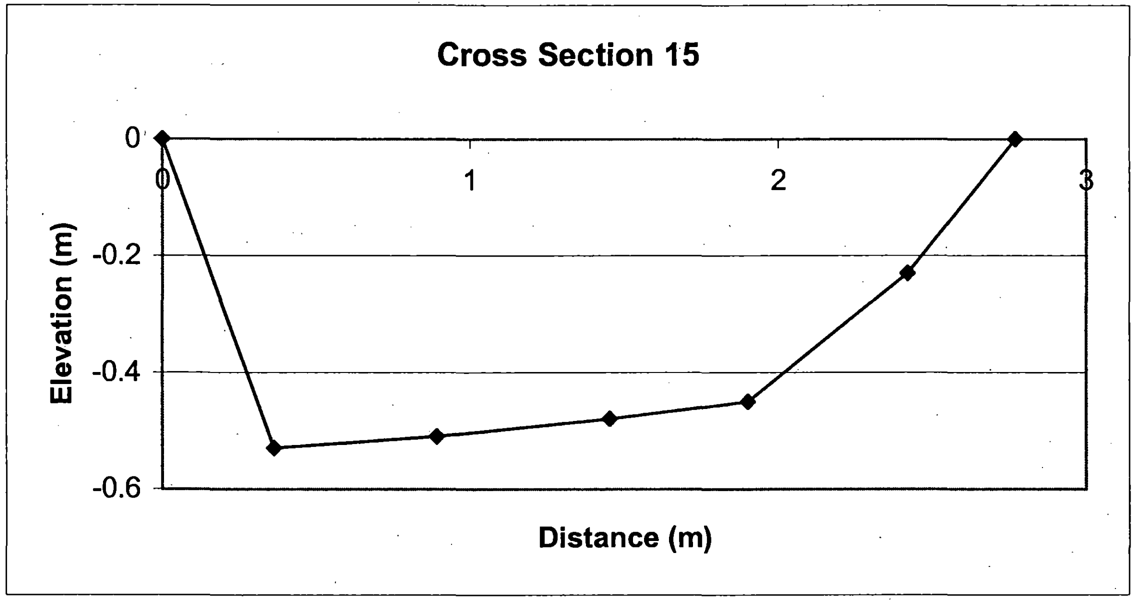
Slope	0.0575
D50 (mm)	59
D84 (mm)	98



X-Section 15

Distance (m)	Elevation(m)
2.77	0
2.42	-0.23
1.9	-0.45
1.45	-0.48
0.89	-0.51
0.36	-0.53
0	0

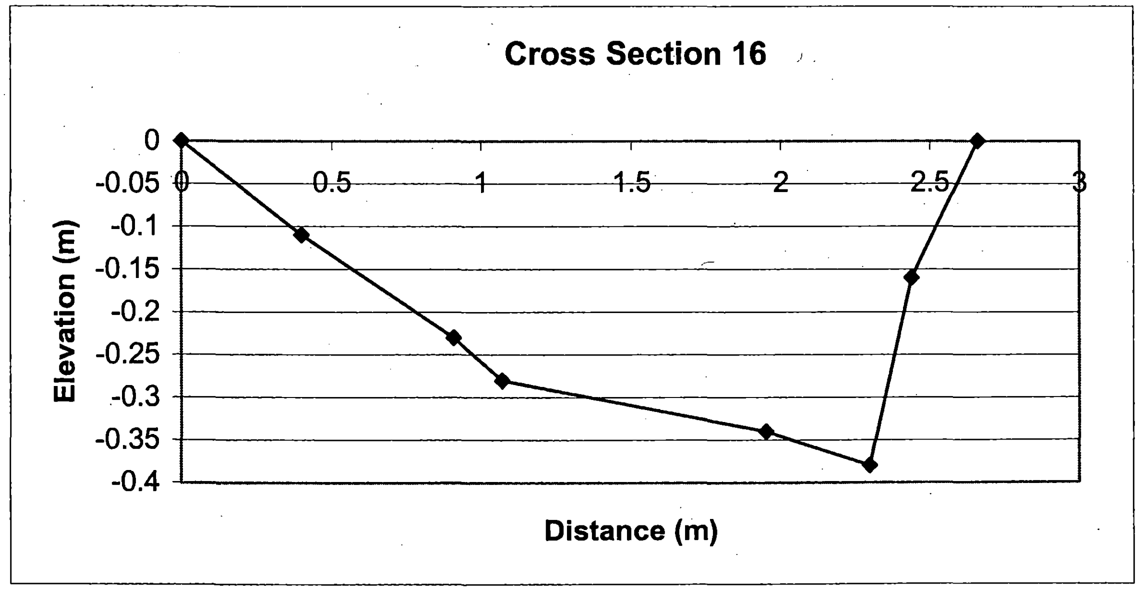
Slope	0.05
D50 (mm)	56
D84 (mm)	97



X-Section 16

Distance (m)	Elevation(m)
2.66	0
2.44	-0.16
2.3	-0.38
1.95	-0.34
1.07	-0.28
0.91	-0.23
0.4	-0.11
0	0

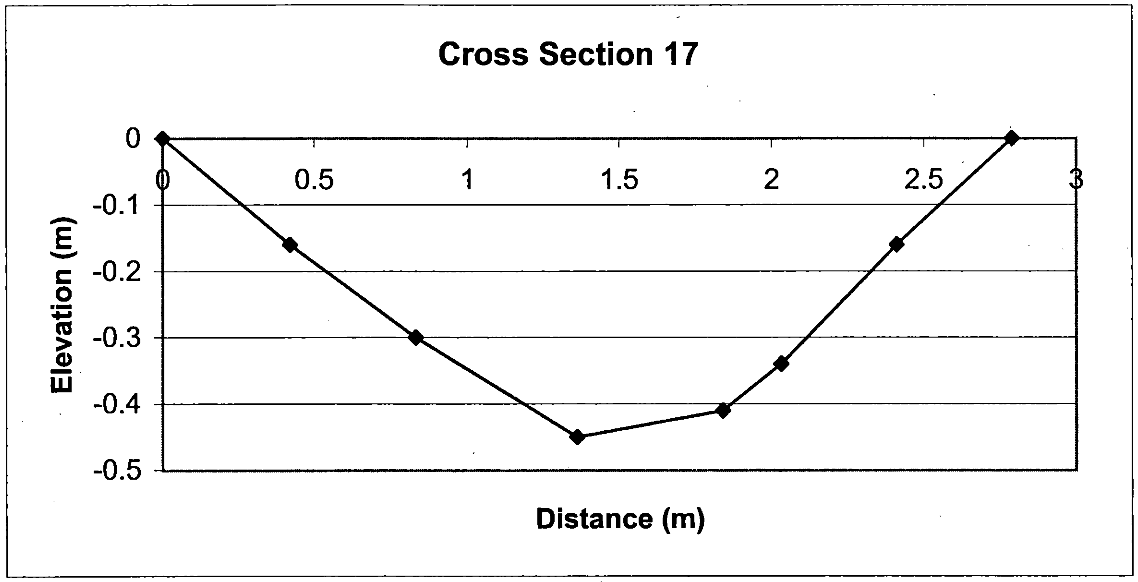
Slope	0.05
D50 (mm)	52
D84 (mm)	96



X-Section 17

Distance (m)	Elevation(m)
2.79	0
2.41	-0.16
2.03	-0.34
1.84	-0.41
1.36	-0.45
0.83	-0.3
0.42	-0.16
0	0

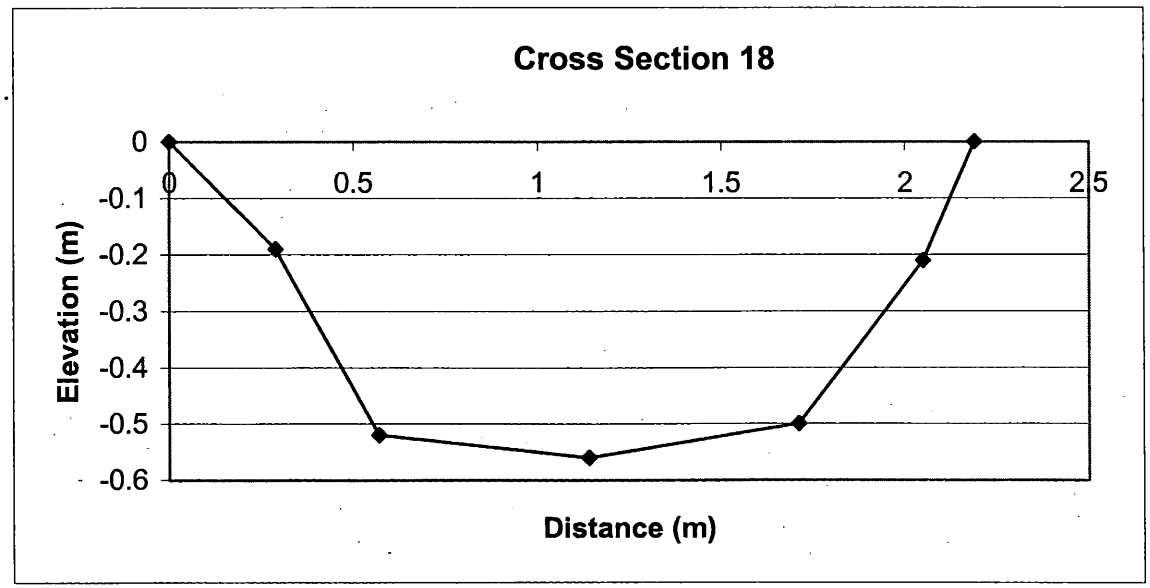
Slope	0.0475
D50 (mm)	54
D84 (mm)	98



X-Section 18

Distance (m)	Elevation(m)
2.19	0
2.05	-0.21
1.71	-0.5
1.14	-0.56
0.57	-0.52
0.29	-0.19
0	0

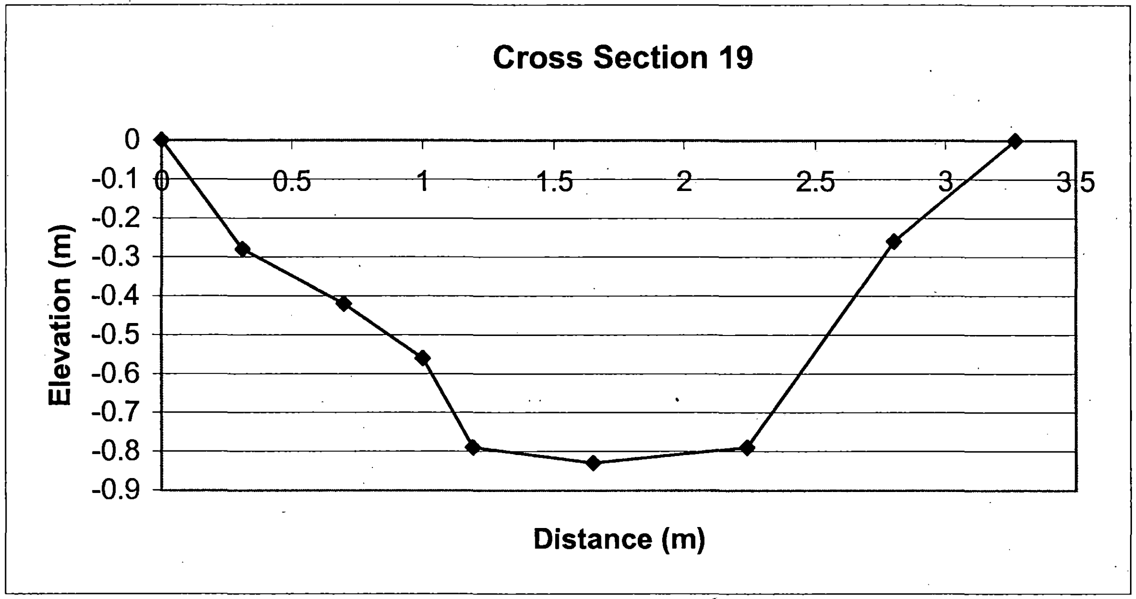
Slope	0.0463
D50 (mm)	55
D84 (mm)	99



X-Section 19

Distance (m)	Elevation(m)
0	0
0.31	-0.28
0.7	-0.42
1	-0.56
1.19	-0.79
1.65	-0.83
2.24	-0.79
2.8	-0.26
3.27	0

Slope	0.0475
D50 (mm)	53
D84 (mm)	96



X-Section 20

Distance (m)	Elevation(m)
0	0
0.51	-0.68
1.02	-0.64
1.67	-0.61
2.05	-0.13
2.25	0